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Quarterly Progress Report

Division 5

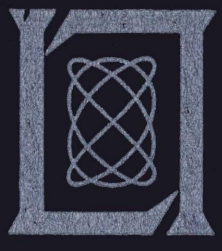
15 March 1959

Information Processing

ASTIA 214566
AFCRC-TN-59-1004

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY



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Division 5

Information Processing

15 March 1959
Issued 25 June 1959

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Lincoln Laboratory
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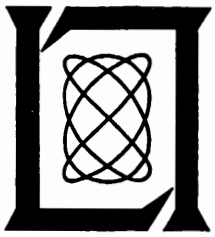
Lexington, Massachusetts



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INTRODUCTION

This is the first quarterly progress report of the Information Processing Division, Division 5. The aims of the Division 5 technical program are:

(1) To develop high-speed, reliable components and devices for logical processing which are cheap in terms of dollars, power and space requirements and are easily assembled into large arrays.

(2) To extend the applications of logical processing to new areas.

(3) To improve, supplement, or supplant present information processing systems.

There are strong interdependencies among the individual projects that make up the program. For instance, in order to exploit fundamental research in materials and components, we have systems readily available in which to test and evaluate the resultant devices and techniques. Further, in order to make progress in the rather speculative area of "self-organizing" or adaptive processes, we must make advances in the assembly of large computing systems and, particularly, in improved techniques for the programming and use of such systems.

On a different level of system complexity, the work of Division 5 supplements and supports the programs of other Divisions of the Laboratory. Information processing is, for example, always embedded in a communication system. In fact, the tie-in between the information processing subsystem and the communication subsystem that supports it has proved to be one of the more difficult problems of large-scale system design. Projects within the Division 5 program are therefore closely coordinated with related projects in the Communications program of the Laboratory. In much the same way, the Systems work of Division 2 influences, and is influenced by, the Division 5 work.

The program of the Division is carried under five general headings. These headings do not reflect the Group structure of the Division. Rather, the technical program interweaves the administrative organization so as to encourage the interactions among a diverse set of projects.

I. MATERIALS AND COMPONENTS

Large, complex data processing systems of the sort currently planned or contemplated assume an era in which logical circuitry is cheap in terms of size, power requirements and basic cost. In fact, the state of the art does not presently support this optimism, and current data processing is component limited. Accordingly, the Division 5 technical program includes substantial effort on fundamental research in the physics and chemistry of materials as well as on projects devoted to the active exploitation of promising leads or techniques for improved components and logical circuitry.

II. COMPUTER DEVELOPMENT

The high-speed, general-purpose digital computer is central to any information processing program. It is the primary "device" in any large-scale, information processing system, and hence an integral part of the equipment-development effort. It also serves as a necessary test bed for new components and new circuits and as an indispensable analytic tool for simulation and experimentation with new techniques and systems.

The program of the Division includes the experimental modification and improvement of two such computers, the TX-2 and the CG 24. It anticipates the design and construction of other computers that will represent as significant an advance in the state of the art as do the present Laboratory machines.

III. DIGITAL DATA TRANSMISSION

If large, netted systems of the sort envisioned, for example, by the Army Automatic Data Processing or the Air Force 480-L (Global Communication) programs are to be developed, a substantial research effort must be devoted to the tie-in of the central processing system with the communication system that supports it. One of the chief technical problems involved is that of the reliable transmission of digital data. In addition to obvious improvements in the transmission links, such as increased transmitter power, it is theoretically possible to detect and correct errors introduced in the channel through the use of redundant coding schemes. Equipment problems in the physical realization of current coding schemes are essentially the same as those found in other forms of logical processing, and such coding systems are under development in Division 5.

IV. ORGANIZATION OF INFORMATION PROCESSES

The advances in digital computing systems of the past few years have been primarily in the areas of increased speed and capacity, with relatively minor changes or improvements in the logic and organization of the elements of the system. One aim of the Division 5 program, however, is to develop new forms of information processing as well as to improve present-day systems. The program includes a diverse set of experimental projects. These projects are in the "new idea" category, where the initial study is typically carried out by a single man. As the study develops, it may absorb more manpower and necessitate a considerable investment in programming or equipment development. The Morse Automatic Decoder (MAUDE), for instance, has reached the stage of being a preprototype system, whereas the "multicomputer system" is in the very early stages of study and, at the moment, involves no equipment or computer time.

V. MAN-MACHINE INTEGRATION

Some of the most obvious and persistent difficulties with present-day information processing systems lie in the area of man-machine communication. Programming is difficult and time consuming. The situation is even less satisfactory in the case of real-time processing systems where the man is expected to evaluate the outcome or, in the case of more sophisticated systems, guide the dynamics of the process. New processing systems and better terminal equipment may alleviate these difficulties. Ultimately, however, information will always be processed by and for men. The Division 5 program supports a number of projects aimed at improving the coupling between the machine and its users.

W.B. Davenport, Jr.
Head, Division 5

F.C. Frick
Associate Head, Division 5

7 April 1959

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1 December 1958 through 1 March 1959

Technical Report

TR No.				Classification Report	Classification Title
197	The Magnetic Properties of Thin Films	J.B. Goodenough D.O. Smith	27 Jan. 1959	U	U

Journal Articles

JA No.			
939	Linear Recursive Sequences	N. Zierler	J. Soc. Ind. Appl. Math. 7, 31 (1959)
1077	Preparation and Properties of the Systems $InFe_xCr_{1-x}O_3$ and $LaFeCo_{1-x}O_3$	A. Wold W. Croft*	J. Phys. Chem. 63, 447 (1959)
1106	Preparation and Crystallographic Properties of the Systems $LaMn_{1-x}Mn_xO_{3+\lambda}$ and $LaMn_{1-x}Ni_xO_{3+\lambda}$	A. Wold R.J. Arnott	J. Phys. Chem. Solids 9, 176 (1959)

UNPUBLISHED REPORTS

Journal Articles

JA No.			
1209	A Transistorized 30-mμsec Pulse Generator	L. Neumann	Submitted to Electronics
1210	The Magnetic Properties of Thin Films	J.B. Goodenough D.O. Smith	Submitted to Am. Soc. Metals (Annual Seminar Volume)
1240	Note on a Singular Function of Minkowski	J.R. Kinney	Submitted to Proc. Am. Math. Soc.
1254	Boundary Behavior of Certain Functions Analytic in the Unit Circle	J.R. Kinney	Submitted to Proc. Am. Math. Soc.
1257	On the Characterization of Orthocomplemented Complete Weakly Modular Lattices	N. Zierler	Submitted to Proc. Am. Math. Soc.

Meeting Papers

Titles of Meeting Papers are listed here for information only. No copies are available for distribution.

JA No.			
1213	On the Band Structure of the b.c.c. Transition Elements	J.B. Goodenough	American Physical Society, Cambridge, 30 March – 1 April 1959
1251	Studies in the Kinetic Depth Effect	B.W. White	American Psychological Association, Cincinnati, 3-9 September 1959
1261	Remembering the Present States of a Number of Variables	D.B. Yntema G.B. Mueser	American Psychological Association, Cincinnati, 3-9 September 1959

* Radio Corporation of America, Needham, Massachusetts.

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DIGITAL COMPUTERS
GROUP 51

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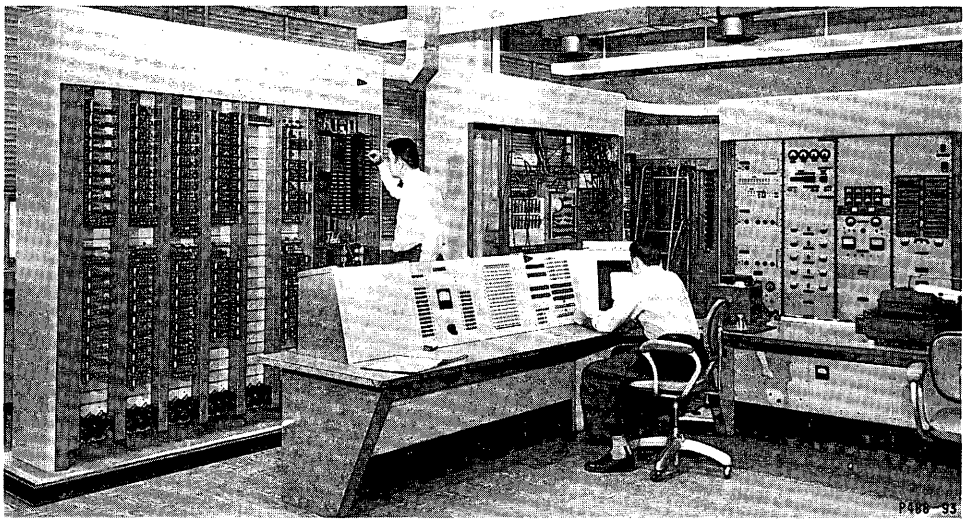

Fig. 51-1. The TX-0 computer installation at M.I.T.

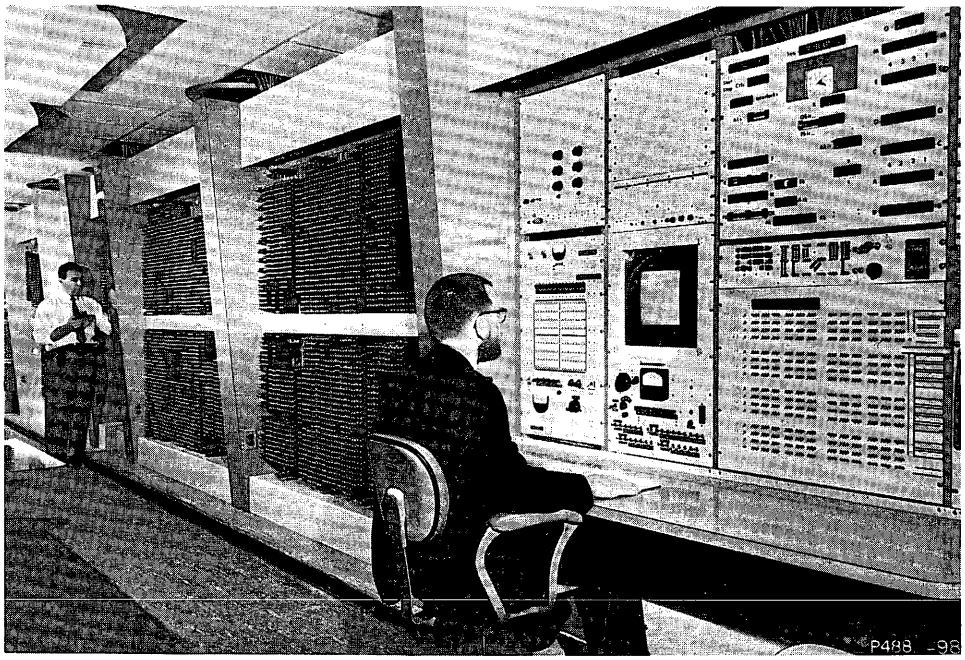

Fig. 51-2. The TX-2 computer maintenance console and main frame.

DIGITAL COMPUTERS
GROUP 51

I. SUMMARY

We are now in the final stages of a computer development program which was based on very large ferrite-core memories and high-speed transistor circuits. A vacuum-tube driven memory of 2.5 million bits and 6.8-μsec cycle time is in operation,[1] and a wide range of 5-Mcps clock rate digital circuits using transistors of the Philco and Sprague surface-barrier family have been developed.[2,3]

Early in the program, a small machine (the TX-0) was built to evaluate the design techniques, circuits, and partially completed large memory.[4] This computer now operates with a 4096-word 6-μsec cycle time transistor-driven memory,[5] also developed within the program, and is installed at the Compton Laboratory of M.I.T. (Fig. 51-1) where it is being operated by the Electrical Engineering Department.

The major accomplishment of the program, the Lincoln TX-2 computer (Fig. 51-2), is a very large and fast general purpose machine for further research and development work in information processing, incorporating many features of design which make it particularly useful for this work. Of special value is the ability of the TX-2 to process data in various word-length configurations.[6]

The TX-2 characteristics are summarized in Table 51-I. Special terminal equipment for various applications will be added to the computer throughout its useful lifetime. The computer has been designed to operate many such pieces of equipment concurrently using a technique termed multiple-sequence control which is based on a design feature of the DYSEAC machine of the National Bureau of Standards.[7,8]

Another small, special purpose machine (the Average Response Computer), which uses TX-2 circuits and packaging, is being operated by the Communications Biophysics Laboratory of M.I.T. with which joint projects in the study of the electrical activity of the brain have been undertaken.[9]

Interconnecting wiring remains a major problem in large scale systems. One promising technique being investigated is the formation of connections between components or assemblies of components by chemical or electrical deposition of metal. An extension to multiple-layer wiring appears feasible. For precision work in the forming of wiring patterns in printed wiring processes, a special machine has been developed which generates geometrical figures on a photographic plate from a coded punched-paper tape.

Large, very fast memory continues to be the most serious problem in digital computer development. The ferrite core has made possible memories of million-bit capacity, with random access speeds of several microseconds. One very promising substitute for the ferrite is the magnetic film, a small evaporated or plated spot of magnetic alloy, about a thousand Angstroms thick. A considerable amount of work over the past two years is now beginning to show some practical results. A 32-word magnetic-film memory is being readied for installation in the TX-2 computer where it will operate with a 0.8-μsec cycle time. Also, a great deal has been learned about the fundamental parameters that control the characteristics of the films, so that it is now possible to fabricate reasonably large arrays of good, uniform quality. The arrays are still largely wired by hand, although some printed circuitry has been tried and evaporated wiring techniques are being examined.

W. A. Clark
B. M. Gurley
W. N. Papian

TABLE 51-I
TX-2 CENTRAL COMPUTER CHARACTERISTICS

General	Parallel transfers, 36 binary digits per word Synchronous timing, 0.2-μsec two-phase clock
Instructions	One single-address instruction per word Addresses are indexable; double indexing is possible Indirect addressing on all instructions can be iterated indefinitely
Operands	Operands can be given a subword configuration based upon 9-bit quarters: One 36-bit operand — Four 9-bit operands Two 18-bit operands — One 27-bit and one 9-bit operand Each instruction specifies a subword configuration, and the arrangement and number of the subwords used
Arithmetic	1's complement binary number system, fixed-point arithmetic From 150,000, 36-bit additions per second to 600,000, 9-bit additions per second From 60,000, 36-bit multiplications per second to 600,000, 9-bit multiplications per second From 14,000, 36-bit divisions per second to 160,000, 9-bit divisions per second Arithmetic instructions longer than one memory cycle can be executed concurrently with nonarithmetic instructions
Memory	65,536 registers of magnetic core memory with 6.8-μsec cycle time 4,096 registers of magnetic core memory with 6.0-μsec cycle time 16 registers of toggle-switch memory 32 registers of plugboard memory 5 registers in the arithmetic and exchange elements Each register, except the last five, has an additional meta (i.e., trapping) bit Instructions and operands can be obtained concurrently Addressing for a total of 131,072 registers of memory provided
Special Memories	64 register magnetic core index register memory, 18-bit word 32 register magnetic film subword configuration memory, 9-bit word

II. COMPUTER DEVELOPMENT

A. TX-0 Computer

1. Introduction

Lincoln Laboratory's interest in the TX-0, the small precursor of TX-2, did not cease when, after two years of test and operation, it was moved out to make way for the newer, larger computer. TX-0's applications, on the M.I.T. campus, continue to be in areas, such as "pattern recognition," which are of considerable interest, particularly to Division 5. Also of importance are data from the machine's operation which will tell us about the life and reliability of its components, particularly its transistors. Approximately 660 of its transistors were retested about a year ago, having accumulated 6000 hours of operation apiece; some degradation was measurable, but all were still within design tolerances and were returned to service.* Another year of operation has been added since those tests, and the retesting is about to start once more.

The results of such tests, as well as a brief summary of TX-0's operations and applications will appear in this report from time to time.

W. N. Papian

2. Operations

The TX-0 computer, which resumed operation under the Electrical Engineering Department of M.I.T. in September 1958 after its move from Lincoln Laboratory, has had extensive use throughout the Fall semester. Table 51-II summarizes the utilization of the computer during the past quarterly period. The emphasis has been in the areas of nonnumerical problems such as pattern recognition and simulation of digital servos, and problems requiring special input equipment, such as the analysis of neuroelectric signals.

The Electrical Engineering Department has purchased an analog-digital encoder and several digital "building block" units for special temporary logic. An additional 4096 words of memory have been ordered but will not be installed until summer. The question of additional computer instructions will be resolved as the memory design is completed.

E. W. Pughe, Jr.
(Electrical Engineering Department, M.I.T.)

B. TX-2 Computer

1. Summary

Control for the arithmetic element was completed in December and the major emphasis has since been in consolidation of the system with those items of terminal equipment necessary for initial program operation. Checking and operation of demonstration, utility, and test programs used about 30 per cent of computer time, increasing throughout the quarter (Table 51-III). Design and installation of new equipment will continue during the next period, and program operation is expected to increase substantially with the beginning of applications work.

B. M. Gurley
J. L. Mitchell

2. Central Machine

With the completion of the arithmetic element control, all 49 of the computer instructions became operational. Temporary power wiring has been replaced and circuit breakers relocated

* D. J. Eckl, P. A. Fergus and R. L. Burke, "Transistor Life Experience: 1954 – 1958," Technical Report No. 199, Lincoln Laboratory, M.I.T. (26 March 1959).

TABLE 51-II

SUMMARY OF TX-0 COMPUTER UTILIZATION
FOR THE QUARTER ENDING 28 FEBRUARY 1959

Use	December	January	February	Quarter
Program Operation (hours)	288	301	291	880
Maintenance and Installation (hours)	77	56	84	217
Total	365	357	375	1097

TABLE 51-III

SUMMARY OF TX-2 COMPUTER UTILIZATION
FOR THE QUARTER ENDING 28 FEBRUARY 1959

Use	December	January	February	Quarter
Program Operation (hours)	51	84	108	243
Maintenance and Installation (hours)	193	207	197	597
Total	244	291	305	840

TABLE 51-IV

DISTRIBUTION OF PLUG-IN UNITS IN TX-2

1. Arithmetic Registers and Control	1056
2. Exchange Element	393
3. Memory Buffering and Addressing	912
4. Index and Configuration Memory Systems	428
5. Control Counters and Central Control	526
6. Input-Output Central	356
7. Input-Output Units	585
Total	4256

in the main frame. Margin checking equipment for the transistor circuits is installed. With the previously installed equipment for the main memory, the margin checking system is completed.

The present count of plug-in units is 4256. These hold a total of 34,611 transistors of all types. In addition, the large memory uses 1320 transistors and 608 vacuum tubes. The distribution of plug-in units among the main elements of the computer is shown in Table 51-IV.

K. H. Konkle
J. L. Mitchell
C. A. Norman

3. Memories

Performance of the 65,536 word memory has been improved by adding feedback to the first stage of the sense amplifiers to increase bandwidth. The 64-word index memory[5] has been working quite well throughout the period. All equipment for the first of the 4096-word transistor-driven core memories (to be used as an experimental addition to the central machine memory) is now in construction, and installation is planned for the near future. The TX-2 addressing scheme leaves room for several more of these units, but only one is presently scheduled.

Provision has been made for 128 words of plugboard, toggle switch, or similar memory. Sixteen words of toggle-switch storage have been in use for some time. Two 16-word plugboard memories have now been installed and add greatly to user convenience. Several test programs and the read-in program have been set up on the plugboards for immediate use.

Parts of the 32-word magnetic-film memory for storing configuration control information are now in construction. The completed system will replace the present temporary configuration memory which consists of 4 changeable words of flip-flop storage and 12 fixed words.

J. M. Frankovich
J. L. Mitchell
L. Neumann

4. Input-Output

Equipment now operating with the computer includes a photoelectric paper-tape reader, low-speed paper-tape punch, cathode-ray-tube display, light-pen photoelectric pickup for use with the display, an input-output typewriter, and the Lincoln Writer keyboard.[10] The high speed Xerographic Printer has been installed and is presently operating with the standard 64-character SAGE stencil in its charactron tube. This tube is to be replaced by a new Stromberg-Carlson charactron, using the newly-designed C7D electron optics and having an 88-character stencil designed to match the Lincoln Writer typeface. A DATRAC analog-digital unit is to be added shortly

With this complement of equipment, initial programming of the computer can begin. Several new pieces of terminal equipment are being designed. Two photoelectric tape readers with simplified handling, high transport speed, and modest start-stop performance will replace the present readers. The prototype Lincoln Writer (Fig. 51-3) which includes keyboard, electric typewriter, mechanical paper-tape reader, and low-speed tape punch should be completed during the coming quarter. Several of these units have been ordered and will replace the flexowriters presently being used for program tape preparation.

A. W. Case
J. T. Gilmore, Jr.
R. H. Gould
C. S. Lin
R. E. Savell
C. E. Woodward

5. Magnetic Tape System

Part of the electronics for the digital magnetic tape system[11] is under construction and the remainder of the electronic parts of the system will be started early in the quarter. The

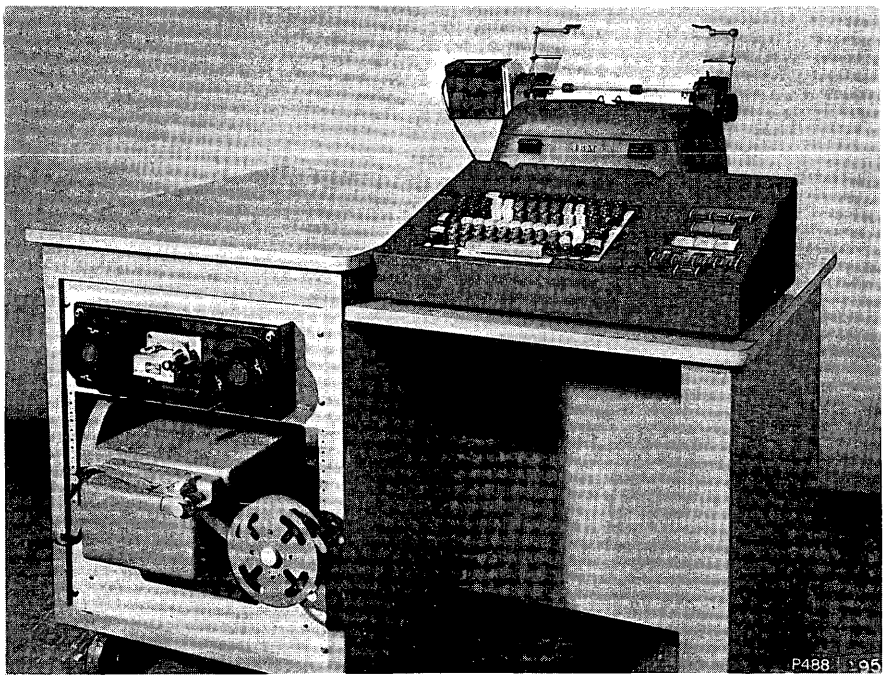

Fig. 51-3. Lincoln Writer prototype.

prototype of the tape transport is now being evaluated, and tests of its operation with the computer should begin during the next quarterly period.

J. E. Laynor
T. C. Stockebrand

6. Programming

Programs exist for three categories: test, utility and demonstration. Test programs have been written for the arithmetic element, the indexing system, the sequence selector, the 65,536-word memory, and for each piece of terminal equipment presently connected to the machine. These will be combined into a single multisequence program which will then be used to exercise the system for relatively long periods of time.

An octal number input utility program, a simple symbolic address assembly program, and a binary tape plugboard read-in program are available for input purposes. Printout programs are being written.

Several demonstration programs are in use. In addition to the customary bouncing-ball display, programs that permit picture drawing on the display scope using the light pen, and limited conversation via the typewriter have been written.

Patricia A. Fergus
J. T. Gilmore, Jr.
R. P. Mayer
H. P. Peterson, Jr.
A. Vanderburgh

C. Plated Component Connections

1. Deposition Process

A method[12] for plating connections between components is under study which may have application in etch-wired circuits. It is most conveniently employed with encapsulated units, but is useful in other forms of packaging as well. Connection densities achievable by the technique appear to be limited only by component size and by the resolution obtainable from photolithographic processes.[13]

Figure 51-4 illustrates the composition of a plated connection. The component lead makes contact to a thin (under 50 micro-inches) layer of chemically deposited copper and, through this, to a thicker (approximately 0.001 inch) layer of electroplated copper. These copper layers are deposited on both faces of an encapsulated unit (where component lead ends appear) and are later selectively etched to become the printed wiring.

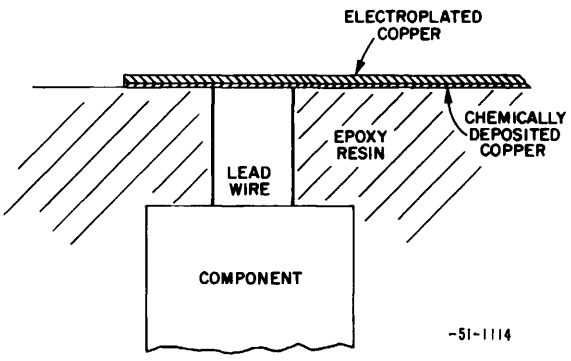

Fig. 51-4. Composition of a plated connection.

Copper is deposited chemically, by procedures based on the early work of Narcus,[14,15] from commercially available solutions. (Connections have also been made[16,17] in which the initial contact layer consisted of chemically deposited silver, gold or nickel.) The sample to be plated is lightly sandblasted, cleaned in acid, then exposed to a sensitizing solution (such as tin chloride), followed by an activating solution (a noble chloride), and finally a copper-reducing solution. The resulting deposit is a fine-grained coating of high-purity copper which adheres well to both the component leads and the encapsulating plastic. Typical bond strengths of 25 lb/inch-wide peel are obtained. Deposition time is 15 to 20 minutes and temperatures do not exceed 100°C. Figure 51-5 is a photomicrograph of a plated connection showing the component lead and the chemically and electrolytically deposited layers of copper. For comparison, a soldered connection is shown in Fig. 51-6.

2. Evaluation Tests

Plated connections have carried currents ranging from a few micro-amperes to several amperes while being subjected to temperature variations up to 380°C, over twice the melting temperature of tin-lead eutectic solder. Numbers of connections per test ranged from 4 to 120 and the tests lasted from 8 to 840 hours (35 days). A room-temperature life test, in which four connections carry 3 amp DC, has been running for over 4000 hours without failure.

A tester was built to supply power and operating pulses to an encapsulated flip-flop with plated connections, as shown in Fig. 51-7, and to count and record the number of times the unit failed to respond properly to driving pulses. Exclusive of power failures and one intermittent plug, the flip-flop has been operating for over six months.

The unit was also vibrated while being monitored by the tester. Vibration was in a direction normal to the etched wiring at frequencies from 10 to 3200 cps for 5-g increments of force until a value of 60 g was reached. Maximum peak-to-peak displacement during the $5\frac{1}{2}$-hour test was 0.2 inch at 75 cps. No errors in operation occurred and the flip-flop was undamaged.

3. Pluggable Unit Package

Figure 51-8 is a drawing of a plug-in unit presently under construction. An important requirement of this unit is that the mobility of the plug pins be retained after encapsulation. The back of the plug is encased in a volume of resilient plastic which is later cast in solid plastic along with the electrical components. Lead wires from the plug are brought up to the surface and treated as component leads. Development plans include the use of foam plastics to reduce weight.

4. Multilayer Deposited Wiring

The four views of Fig. 51-9 represent successive steps in the construction of multilayer deposited wiring. To the board shown at the upper left, a deposited and electroplated "ground plane"

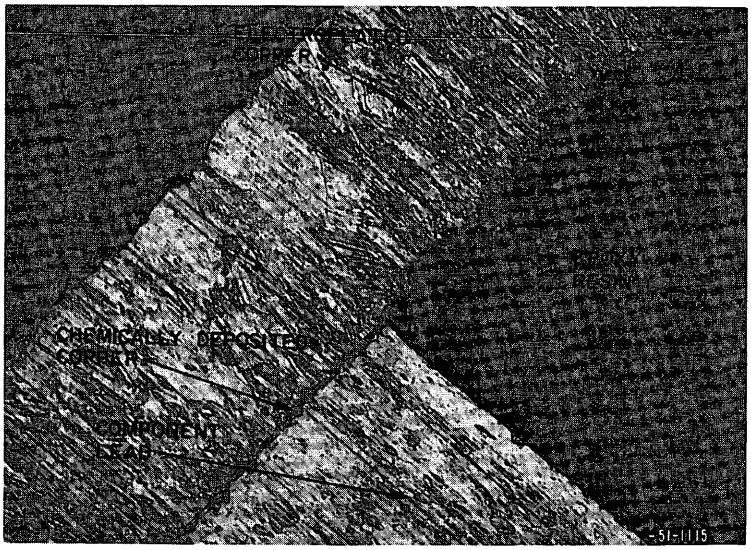

Fig. 51-5. Photomicrograph of a plated connection at 315X magnification (on 4 × 5 inch plate).

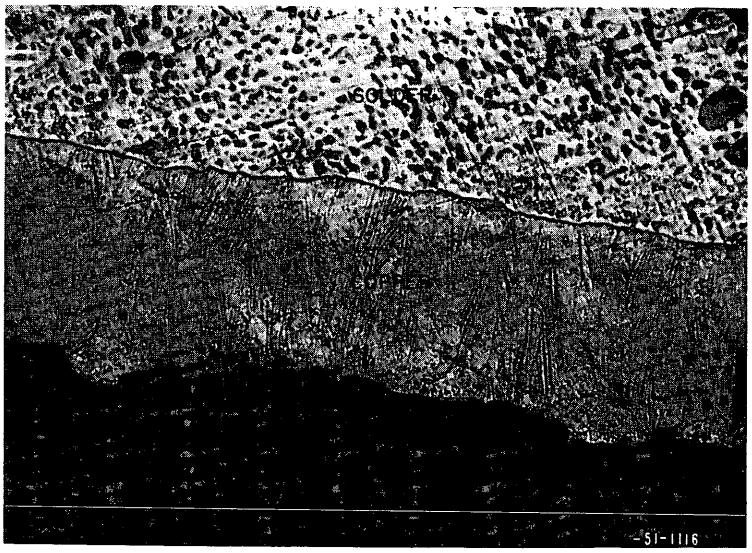

Fig. 51-6. Photomicrograph of a soldered connection at 315X magnification (on 4 × 5 inch plate).

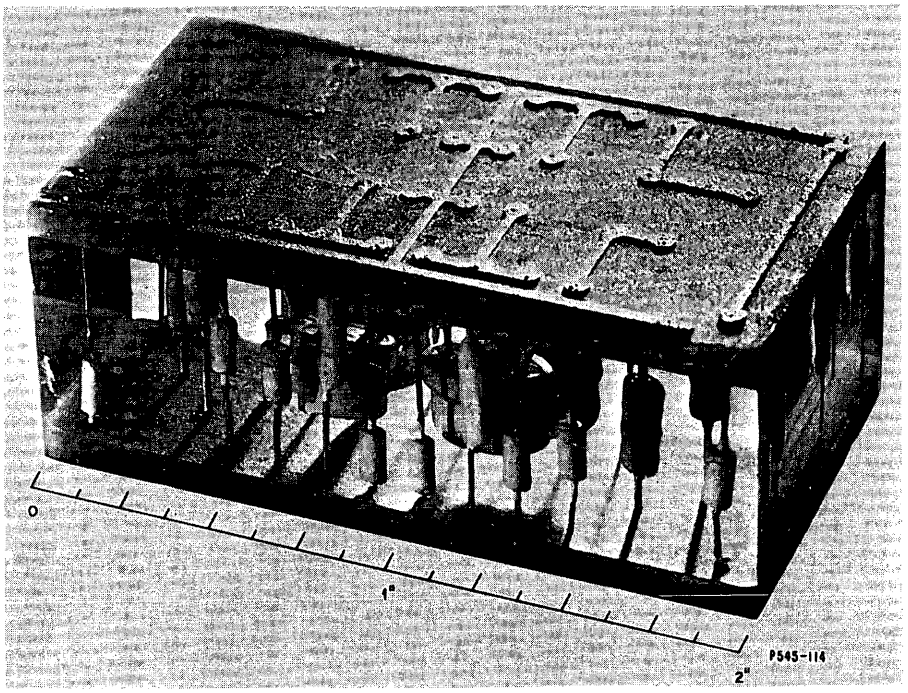

Fig. 51-7. Encapsulated electronic circuit with components interconnected by plated connections and etched wiring.

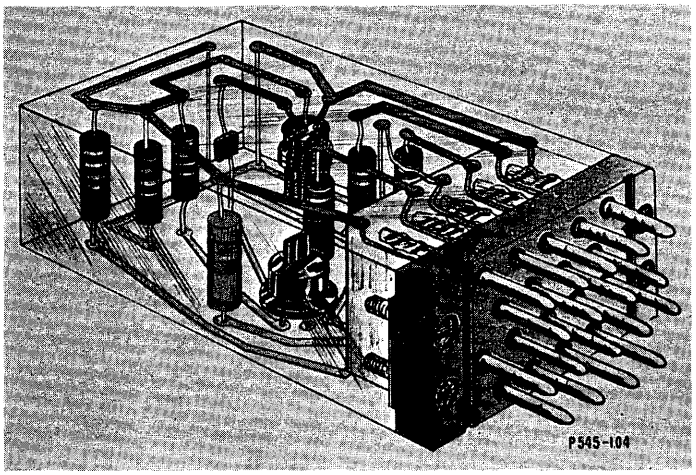

Fig. 51-8. Drawing of proposed plug-in unit employing plated connections.

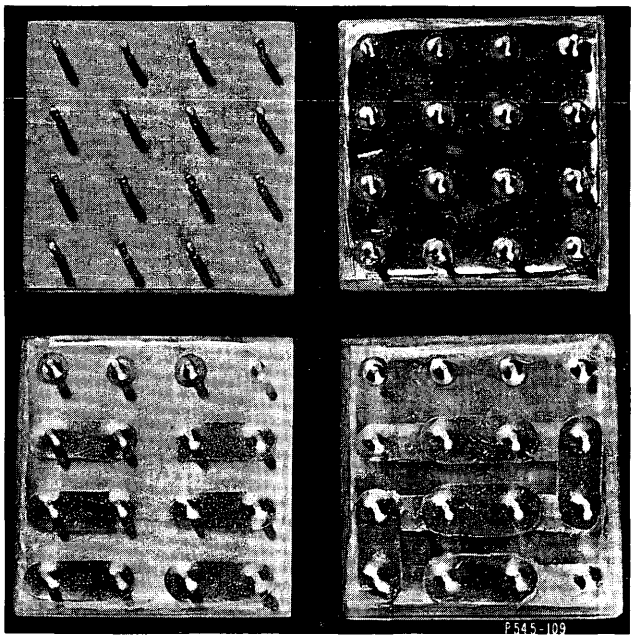

Fig. 51-9. Successive stages in production of multilayer deposited wiring with plated connections to copper pins (upper left to lower right).

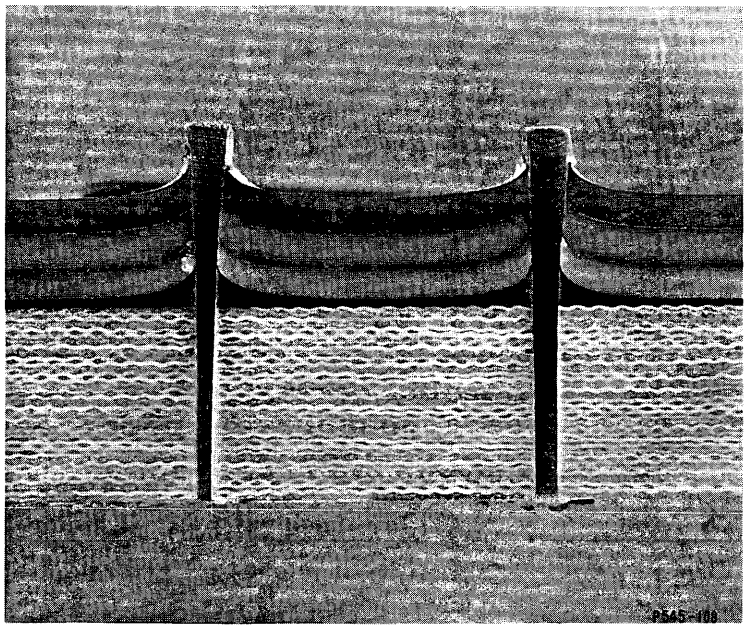

Fig. 51-10. Section view of multilayer deposited wiring with plated connections to copper pins 0.5 inch apart.

has been added which is connected to a corner pin by a plated connection (upper right). All other pins have been isolated from the ground plane by a photoetch operation. A thin layer of epoxy resin over the ground plane supports a set of deposited photoetched conductors that join pairs of pins together by plated connections (lower left). A second layer of resin supports additional deposited photoetched conductors that join the unconnected pairs of pins to form a two-level series circuit over the copper ground plane (lower right). Figure 51-10 is the photograph of a finished board that was cut, sanded and polished to show the half-pins and four layers of conductors and connections. The technique makes possible the deposition of strip "transmission line" in which the characteristic impedance is a function of the conductor width and the thickness of the insulating plastic. Layers of epoxy resin 0.015 inch thick have been laid down on a 10 × 12-inch board, with thickness controlled to plus or minus 0.001 inch. Each consecutively cured layer consists of a measured weight of fluid resin poured onto the board (surrounded by a fence) while it rests on a level stand in an oven.

A proposed application of multilayer transmission-line wiring with plated connections is pictured in Fig. 51-11. Shown are encapsulated units plugged into a wiring board module containing two separate levels of "transmission line" wiring. Plug receptacles extend to the rear of the board as pins of sufficient length to accommodate the number of wiring levels required. Each layer of ground plane, dielectric, and conductors can be processed and tested consecutively. A proposed subassembly for an electronic computer would consist of a frame-mounted "board" of deposited wiring (and associated plug-in units) interconnected by plugs and cables to the other boards.

D. Semiautomatic Wiring Pattern Generator

The semiautomatic wiring pattern generator is a converted milling machine which moves a photographic plate, or film, under a small-diameter light source to produce an accurate conductor pattern for precision etched-wiring work. A line may be exposed anywhere on the 8 × 10-inch film to a position accuracy of plus or minus 0.001 inch from an edge reference line. For patterns requiring accurately positioned discontinuous straight lines, the light source can be controlled by a punched paper tape. Figure 51-12 shows the light tube positioned over the vacuum table that holds the film to be exposed. The tape-reader mechanism is mounted on the extreme right of the traveling table and is powered from the table drive and geared so that the tape moves 100 times faster than the table. Holes previously punched in the tape are sensed photoelectrically and cause the printing light to be turned on and off at appropriate positions on the film. Figure 51-13 shows a roll of punched tape, together with several light nozzles of various sizes. Typical patterns produced on the machine are illustrated in Fig. 51-14.

E. A. Guditz

III. MAGNETIC FILM ENGINEERING

A. Magnetic Film Memory

The investigation of magnetic films for use as binary storage elements is motivated by their low flux, their low-field high-speed rotational switching, and potentially inexpensive manufacture and wiring. It is no longer necessary to handle individual cores, and much higher densities become possible.

An experimental memory[18] using $\frac{1}{16}$-inch circular spots, 600 Å thick and spaced ten to the inch, has been constructed. The memory contains 32 ten-bit words on two pieces of glass, each holding a 16 × 16 array of spots (some spots are not used). The word length is determined by

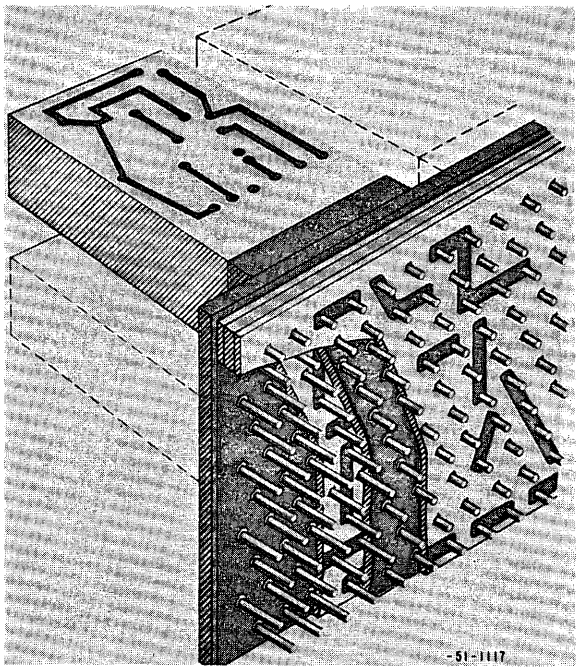

Fig. 51-11. Proposed module of plug-in unit interconnecting wiring. The multilayer transmission-line deposited wiring with plated connections is shown.

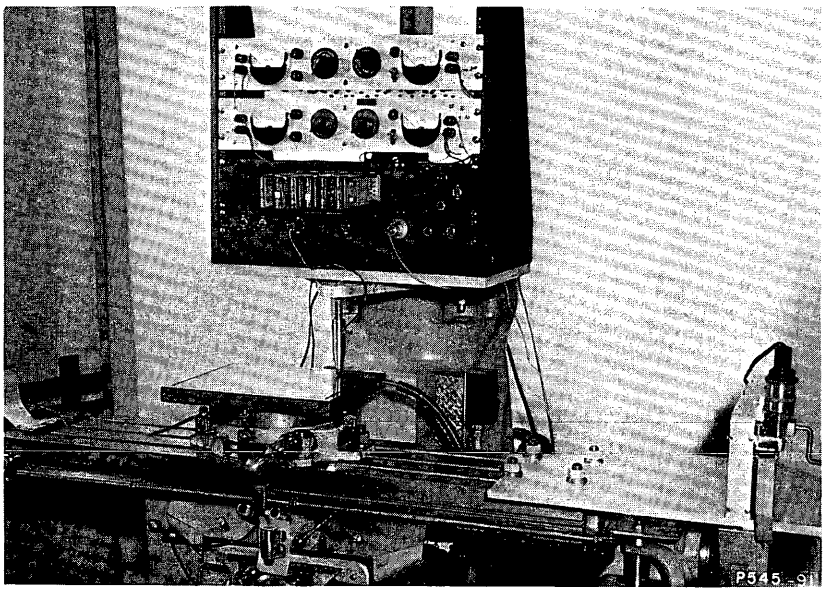

Fig. 51-12. Semiautomatic wiring pattern generator.

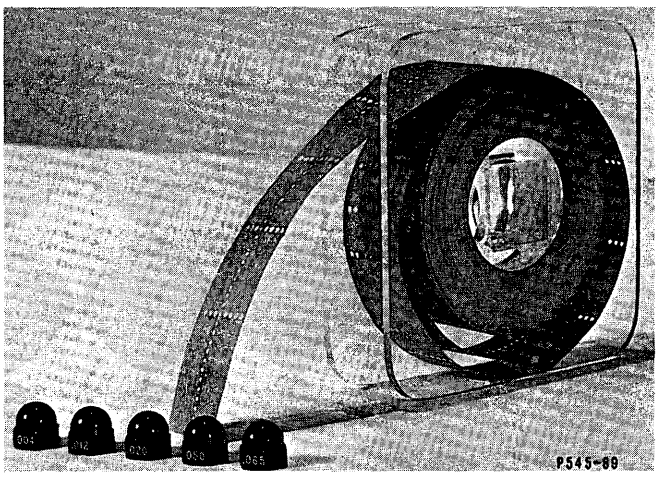

Fig. 51-13. Punched paper tape and light nozzles for semiautomatic wiring pattern generator.

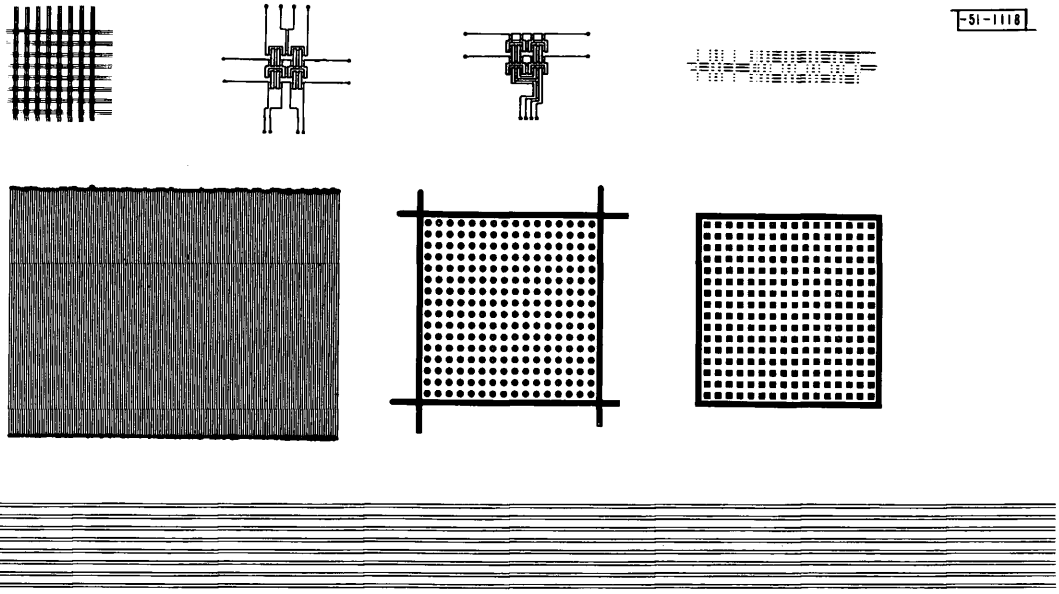

Fig. 51-14. Typical patterns produced on the semiautomatic wiring pattern generator.

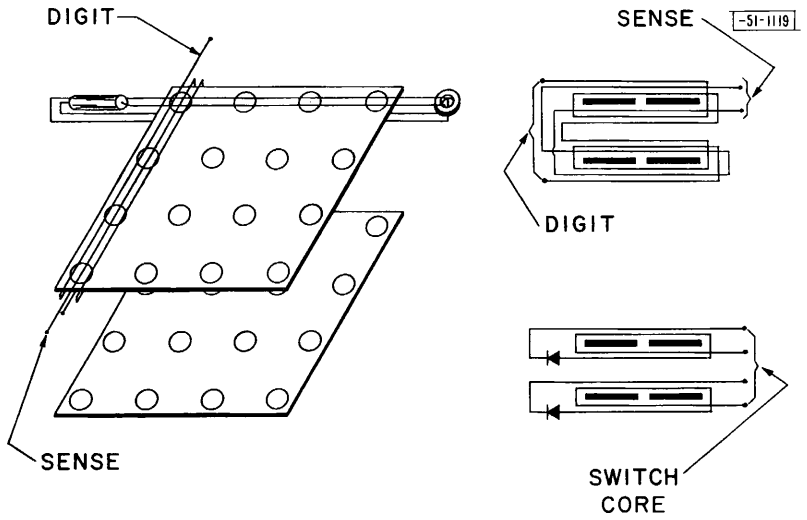

Fig. 51-15. Magnetic-film memory assembly.

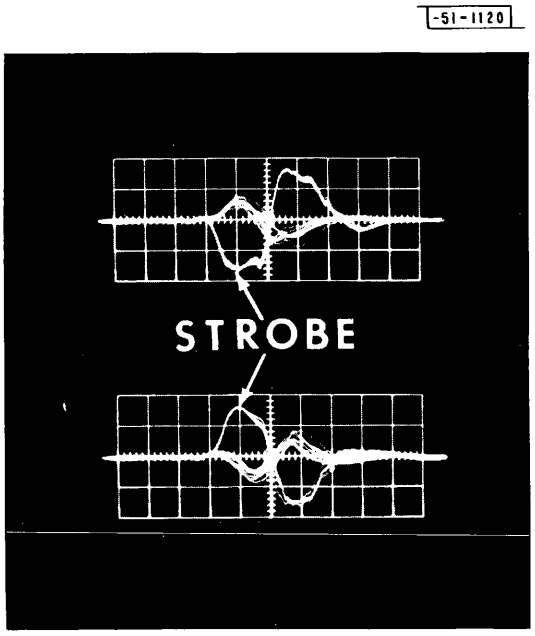

Fig. 51-16. "One" and "zero" outputs for halves of sense winding (0.1 μsec/division).

the TX-2 computer configuration-control element for which this memory was designed. It will operate with a cycle time of 0.8 μsec in the computer and has been run experimentally with cycles from 0.4 to 0.5 μsec in duration.

A two-coordinate switch using zinc-magnesium-manganese ferrite cores provides a 250-ma 0.25-μsec pulse into the selected two-turn winding linking a single word (Fig. 51-15); the field produced is transverse to the easy direction of magnetization of the films. Another two-turn winding links each digit of the memory and determines the information to be written by applying a longitudinal field in the "one" or the "zero" direction.

The longitudinal excitation for reading or for writing a "zero" consists of 150-ma DC in the "zero" direction. Reading is accomplished in the first half of the cycle by energizing the selected word with a transverse pulse in the presence of this DC excitation on all digit lines.

Wherever a "one" was held a positive pulse is induced on the sense winding as the film rotates to the "zero" state. If a "zero" was held, a smaller negative pulse occurs due to partial rotation toward the transverse direction. At the end of the read half of the cycle the selected word contains all "zeros." Writing "ones" is accomplished, halfway through the transverse pulse, by turning on the desired digit drivers to superpose a 300-ma current in the "one" direction on each desired digit line. "Zeros" will remain where no digit-driver pulses appear, since the 150-ma DC currents flow in the "zero" direction continuously through the digit windings.

The sense winding is crossed-over in the center of the memory to yield balanced areas for zero coupling to the digit winding, to which it is parallel. This provides bipolar signals to the sense amplifier; in order to correctly interpret "zero" signals which are sizable, but opposite in polarity to "ones," it is necessary to have the address determine which side of the balanced amplifier is interrogated (Fig. 51-16).

Since all of the conductors are straight lines, it is possible to construct the wiring matrix by winding No. 36 wire, with the aid of a slotted jig, over sheets of fiberglass or plexiglass and cementing the wire to the sheets (Fig. 51-17).

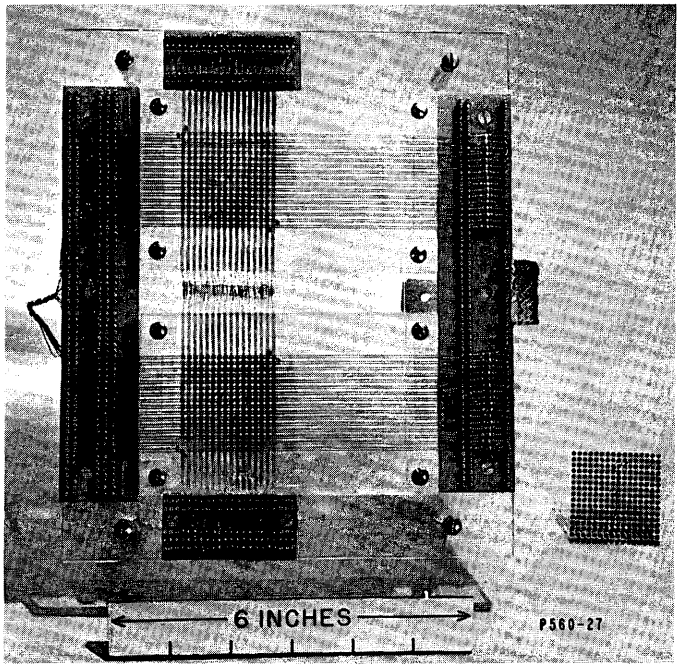

Fig. 51-17. Magnetic-film memory wiring matrix.

In the original design, each core-switch secondary was terminated in a resistor; the noise currents from the switch in this arrangement are sufficiently large to cause a gradual deterioration of information. Furthermore, the resistive termination provides a positive-negative pulse pair from the core. Although the first could be used for reading and the second for writing, the resultant operation was slower than that afforded by sharing a single transverse pulse for both reading and writing. The use of a diode in the secondary blocks the second pulse, and the diode nonlinearity eliminates the small noise currents from the core switch. A CTP-592 diode is used; its forward resistance is about 2 ohms at 250 ma.

J. Raffel

B. Evaporation of Permalloy Films

1. The Uniformity Problem

The production of arrays of spots for magnetic film memories requires an understanding of the factors in the deposition process contributing to magnetic properties and, in particular, of the key parameters controlling the wall coercive force H_c and the anisotropy field H_k.

For the films that at present seem to be most interesting for memory applications, the variability in H_c and H_k has been shown[19] to depend primarily upon substrate cleaning, evaporation rate and angle of incidence of the depositing vapor. All of these factors can vary within a run as well as from run to run. To minimize the variability due to these factors, the evaporation process now incorporates a number of new features.

2. Glass Cleaning Procedure

Glass is placed in teflon holders and agitated for 10 minutes in a 400-watt ultrasonic tank containing 15 cm^3 of Alconox in 3 gallons of distilled, demineralized (abbreviate "D.D.") water heated to 150°F with an immersion heater.

Holder and slides are sprayed with D.D. water from a wash bottle before the first 10-minute rinse in a 60-watt ultrasonic tank filled with 1 gallon of 150°F D.D. water.

The second ultrasonic rinse is identical to the first, but done in a separate 60-watt tank. It is preceded and followed by the wash bottle spray rinse. Drying is done in a filtered air cabinet under a heat lamp.

3. Moving Substrate

The substrate holder is capable of lateral motion in two directions. In one direction of travel, motor drive through a rotary seal provides reciprocal motion. This sweeps a row of slides back and forth over an aperture one slide in width. The impinging beam is therefore confined to a much smaller angle than in previous experiments. When a row of slides is finished, hand cranking through another rotary seal moves the substrate over and the next row is evaporated. The resultant skew revealed by pulse testing the small spots seems to be much less than that obtained with wide angle beams.

4. Aging Effects

One hundred specimens, fabricated over a period of a year, showed no noticeable aging effects in the 6-month interval between tests.

5. Production Unit

A manipulator for the vacuum system capable of handling about fifty 16 × 16 planes in a single-run evaporation is being planned. The mechanism will be similar to the feed on an automatic slide projector.

T. S. Crowther

C. Testing and Instrumentation

1. Hysteresis Loop Tester

The main instruments for evaluating films are a low-frequency (1000 cps) hysteresis looper and a pulse tester.

The hysteresis looper is used on single $\frac{1}{2}$-inch spots and for taking gross average measurements of arrays of small spots (Fig. 51-18). The present looper does not have the sensitivity needed for testing single $\frac{1}{16}$-inch spots, but it is hoped that this will be achieved in the future.

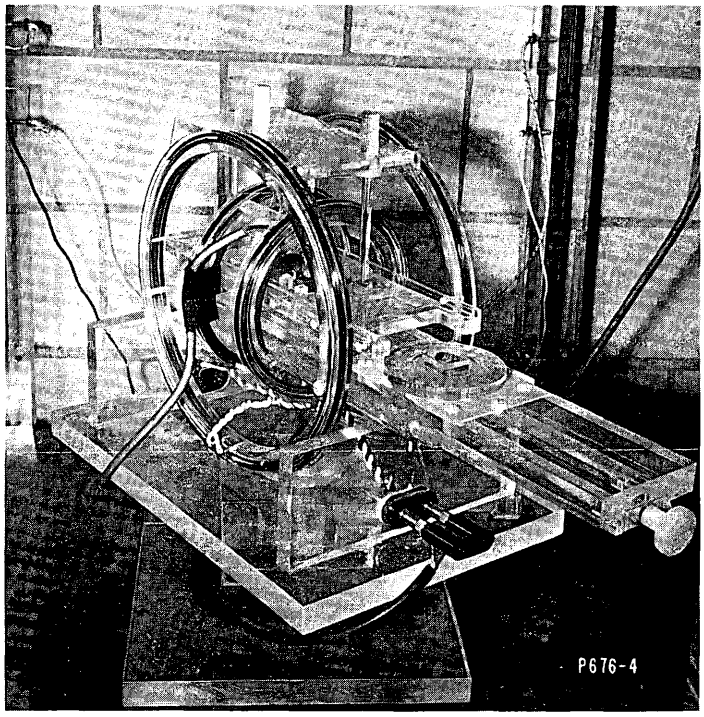

Fig. 51-18. Hysteresis loop tester.

The looper is conventional in design. A pair of Helmholtz coils provides an alternating 1000-cps field. The sample is placed under a 5000-turn pickup coil which is in series with a similar coil for bucking air flux. Balance is obtained by mechanical positioning of the bucking coil until there is a null, except for a small component in phase with the drive current which is then balanced out by introducing a controlled amount of the drive current into one input of the scope difference amplifier and the signal into the other. The large inductance of the pickup coil tends to shift the phase of the signal, especially when a resistor is placed across the coil to damp out the ringing due to high-frequency signal components that excite the natural frequency of the coil. The phase shift of the voltage signal may be compensated by deliberately shifting the phase of the current signal a like amount.

To eliminate random high-frequency tube noise at high gain, it is best to place the integrator after some amplification so that it acts as a low-pass filter. Sixty-cps noise can be eliminated by triggering the scope unblanking circuit from the line, so that one trace is displayed for each cycle of line voltage. Some random low-frequency noise (about 2 cps) has so far resisted attempts at elimination.

The measurements of principal interest are saturation flux, anisotropy field H_k and wall coercive force H_c. The latter can best be measured by looking at the unintegrated output at lower frequencies (10 to 100 cps). Direction of easy axis can be determined within ±1° by rotating the sample in the looper and obtaining a null for a field applied perpendicular to both the pickup coil and the easy axis of the film.

2. Pulse Tester

The pulse tester consists of a plexiglass block, in one face of which are embedded two orthogonal pairs of drive lines. Vacuum-tube drivers supply current to the lines, producing pulsed fields of transverse and longitudinal excitation to the films. A pickup coil of 10 to 15 turns of very fine wire wound on a 30-mil dowel is held in a plastic cylinder which fits into a hole above the intersection of the drive lines.

A plane is moved under the crossed wires and coil by the motion of a block on which it lies and which is indexed in steps of 0.100 inch along a set of ways (Fig. 51-19). The metal block forming the ways is located in another set of ways at right angles, providing 0.100-inch steps in the perpendicular direction. It is possible with this arrangement to step through a plane, spot by spot, and have all 256 spots registered with respect to coil and drive lines.

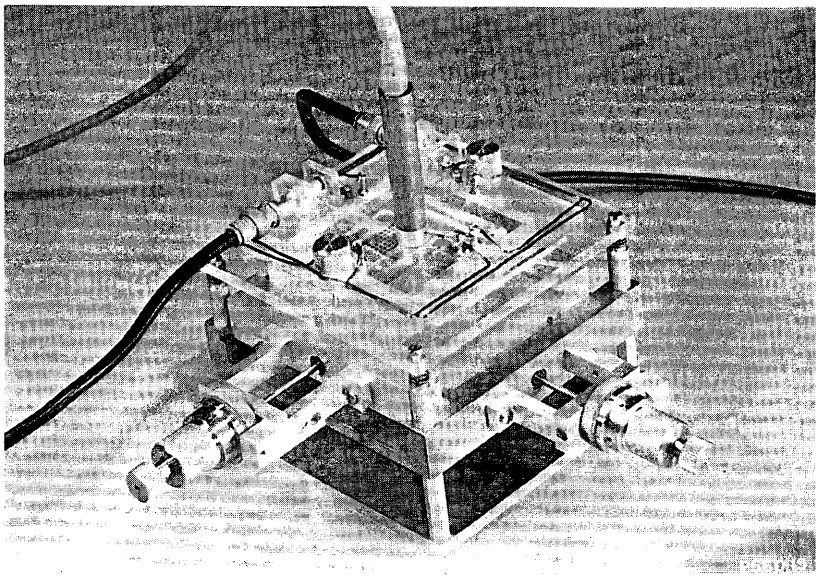

Fig. 51-19. Magnetic-film pulse tester.

Three main tests are given each spot. One test determines the skew of the spot, by measuring the output due to rotation from the "one" and then the "zero" direction. At zero skew these are equal. A second measures pulse output amplitude under normal memory operating conditions. This gives a measure of flux and H_k uniformity. Third, a measure of wall thresholds is obtained by applying bursts of longitudinal disturbing pulses, and varying the amplitude until the readout signal begins to deteriorate.

The effect of the nonuniformity of field produced by the two drive wires has been measured by comparing it to a ten-turn uniform-drive configuration. The main effect seems to be a lowering of the wall threshold value.

J. Raffel
D. D. Strassberg
R. C. Zopatti

D. Circuitry

The circuits developed for magnetic-film memory applications are all transistorized. The driver-decoder package uses three L-5432 (Philco Corporation) transistors to supply about 350 ma with a rise time of 20 to 30 mμsec. Four decoder transistors are included in the package.

The sense amplifier uses 2N501 transistors in three cascaded difference-amplifier stages, and has a gain of about 1000. The output goes to a strobe circuit that then feeds directly to a high-speed flip-flop which can control the digit-plane driver.

At present, a core matrix is used to provide the transverse pulses, but a diode switch is being designed to do the same job. The main question at present is whether the switch will capacitively couple too much common-mode signal to the sense winding, since it is no longer possible to ground all the transverse lines as could be done with the core-switch secondaries.

H. Blatt
T. O. Herndon

E. Electrodeposition of Magnetic Films

The General Electric Company subcontract for investigating electroplated magnetic films was intended to provide information[20,21] about the fundamental physical properties of plated films and to explore a deposition technique that might prove superior to evaporation.

Early in the work, both here and at the General Electric Company, it became clear that the sputtered gold substrate upon which the Permalloy was plated was a controlling factor in determining the magnetic properties. For example, thin magnetic films with low H_k could not be produced at first; this could be accomplished, it was found, when the thickness of the gold substrate was substantially reduced. It was also found that, by increasing the voltage at which the gold is sputtered, it is possible to raise the wall coercive force without affecting H_k.

No completely satisfactory masking technique for large arrays has been found; photoresist appears to adversely affect the magnetic properties of the film. However, single $\frac{1}{16}$-inch spots have been made which behave like evaporated spots under pulse conditions.

J. Raffel
D. D. Strassberg

IV. INFORMATION PROCESSES

Quantitative electrophysiology is a rich field for the development and use of new information processes; in turn, any resultant insights into the organization of the central nervous system will be of considerable interest to the computer field. We have been cooperating with the Communications Biophysics Laboratory at M.I.T. in exploratory work on the electrical activity of the brain.

In this study there are two main problems. The first is to find what regularities exist in the extremely complex electrophysiological waveforms, and the second is to construct adequate models to describe the regularities that have been found.

Early work in model construction in this area was carried out on the Lincoln Memory Test Computer.[22,23] The model studied was a randomly connected net of nonlinear elements, each possessing many of the known characteristics of neurons. It was shown that gradual modification of the "coupling constants" between the elements according to a very general rule caused the net, with suitable training, to reorganize itself to discriminate between two different inputs. It was further shown that the net would then, without further training, tend to classify inputs

together if they possessed elements in common, thus effecting a primitive "generalization" of learning.

More recently, using the Lincoln TX-0 computer, regularities in the electroencephalogram have been studied.[24] Establishment of these regularities was based on an old idea that EEG patterns known as "rhythmic alpha bursts" have significance. A process was developed which detected rhythmic alpha bursts reasonably well. Measurement of the rate of occurrence of the bursts and the total time occupied by them exhibited significant variation with individual subjects, and with different states of the same subject.

In addition, the studies show the feasibility of using a digital computer for scientific work in these areas, provided the computer is a very capable one, properly used. The Lincoln TX-2 computer system, because of its unusual memory size, speed and flexibility, will be the most advanced tool in existence for studies of the quantitative behavior of the brain. Accordingly, preparations have been made during the past quarter to use TX-2 to extend and broaden the preliminary work mentioned above. The attack in the model building area will be to try various neural nets with different topological and connection properties, in an attempt to acquire a "feel" for the dynamic properties of such systems. It should then be possible to synthesize systems with behaviors that can be experimentally tested. Further work on electroencephalogram analysis will be carried out with particular attention to detecting responses to various external stimuli.

W. A. Clark
B. G. Farley

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DATA PROCESSING
GROUP 52

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DATA PROCESSING
GROUP 52

I. INTRODUCTION

The program of Group 52 consists of efforts in three related areas:

(a) Development of special solid state computer circuit components,

(b) Research on methods of encoding digital data for reliable transmissions over communication channels,

(c) The design of digital data processing systems for various applications.

Progress during this quarter on that part of the Group's program concerned with the CG 24 Computer and the Laboratory's AICBM effort has been reported in the AICBM Quarterly Progress Report and is not included here. Previously, this program has been included in the Division 3 Quarterly Progress Report under Group 32.

II. MEMORY DEVELOPMENT

A. Introduction

Memory efforts within Group 52 have been primarily directed at obtaining a considerable speed improvement while utilizing presently available magnetic elements or materials. A new mode of operation called impulse switching, produces a partial switching process within the magnetic element and provides switching times below 50 mμsec. Ferrite cores are currently being used for convenience as the storage elements, but impulse switching may be applied to other magnetic elements.

The process of partial switching is not completely understood and a program to investigate this process is being conducted. However, practical use of impulse switching is presently finding several outlets.

First, a 1000-word, 80-bit, 0.5-μsec cycle time memory is being designed and constructed for Group 47 to provide a practical demonstration of the applicability of this method of core switching as well as to provide a useful tool for radar data processing experiments. In addition, applications of impulse switching to other areas, such as core matrix switches, shift registers and multistate storage, are under investigation.

The measurement of heating of ferrites operating at megacycle rates has been inconclusive. One method of measurement agrees with the theoretical calculations but a second method does not. Additional effort will be made to establish the exact heating.

The memory circuitry required for random access and other applications is being studied. The effort to date has utilized the negative resistance devices (p-n-p-n diodes) that offer all the advantages desired except fast recovery. Various recovery techniques have been employed with moderate success, but no final design has been achieved. Improved p-n-p-n devices are being received from the manufacturers and it may not be necessary to devise elaborate circuit techniques to obtain the circuit operation desired.

Additional test equipment has been built to extend the magnetic measurements. A B-H loop plotter has been designed and will be reported in a following section.

A memory tester has also been constructed for Group 314 to check the CG 24 memory cards. A reasonably complete testing procedure has been developed for each circuit and is proving quite useful.

R. E. McMahon

B. Magnetics Research

During the past quarter, the work in magnetics research has been concerned with further investigation of the impulse switching mode of operating ordinary ferrite cores. One aim of this work was to extend present knowledge of core properties related to high temperature and high-frequency operation. Also, emphasis has been placed on experimental attempts to answer questions concerning the mechanism of the partial switching phenomenon.

An important consideration in extending the present sequential method of operating an impulse core memory to a random access mode of operation is the change in properties of the cores due to hysteresis losses when the core is operated at very high frequencies. The switching waveforms of RCA XF3018H cores when switched at a 5-kcps rate and at a 1-Mcps rate were compared. Circuits were constructed so that when the frequency was changed between 5 kcps and 1 Mcps, the rise time and the amplitude of the input current pulses did not change. Data for various degrees of partial switching were taken; an example of the results follows. For one test the core was partially switched during the write cycle with a current of sufficient amplitude and width to switch 67 per cent of the flux of the core at room temperature and at a 5-kcps rate. When the frequency of the operating cycle was increased to 1 Mcps, the higher losses within the core increased the temperature of the core such that the write current was now capable of switching 88.5 per cent of the total flux of the core. Temperature tests on the same core with the same write current as above were run. With the core operating at a 5-kcps rate and at room temperature, the write current switched 67 per cent of the total flux out; when the core was placed in an oven and heated to 300°F, the write current was able to switch practically all the core. The increase in the peak amplitude of the switching waveform with increased temperature is due to increased speed of the switching process and also to additional flux switched. An accurate determination of the relation between the operating frequency and the associated temperature changes is difficult.

One point of basic interest concerns the mechanism of flux reversal in ferrite cores under high drive currents. Accurate tests were made on type 50-80 S-1 cores to obtain the time required for a complete flux reversal of the core during read time for various drive currents. A plot of the inverse switching time vs applied current is shown in Fig. 52-1, and it can be seen that the curve consists of two linear regions. The core appears to have two different switching coefficients depending upon the level of the drive current. The data for this curve were taken with the read and reset (write) currents of equal amplitude and width. If the reset current is held at a very large value (about 3 amp), the difference in slopes of the two regions becomes very small. This change in results indicates that the lower region of the curve is one where not all the core material is being switched; and the switching coefficient might therefore change when the drive becomes sufficient to cause saturation throughout the entire core.

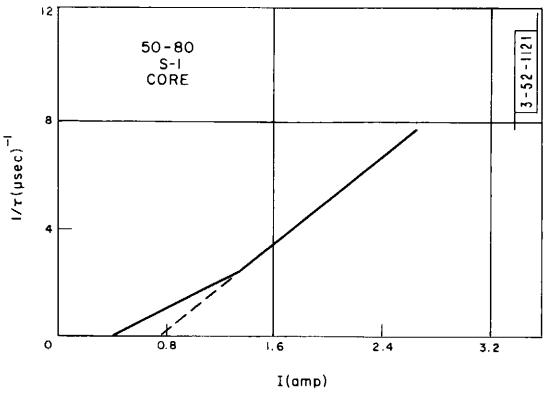


Fig. 52-1. S-1 core.

A simple mathematical model was used to describe the motion of a single domain wall moving away from the center of the core at a rate proportional to the driving field at that point, i.e.,

$$\frac{dr}{dt} = K(H - H_o) \quad ,$$

where H is the field at the position of the domain wall, r is the distance of the wall from the drive wire and H_o is the intercept of the switching curve with the abscissa. The coefficient K remains to be determined. The solution of this differential equation, plotted in Fig. 52-2 for a large core, exhibits a very definite break in the region of the experimental break. The experimental switching coefficient was measured in two ways: (1) defined the switching time as the time that the rate of change of flux was above 10 per cent of its peak value, and (2) defined it as the time required for the flux to change from 10 to 90 per cent of its total value. The break occurs at the same drive current for both curves.

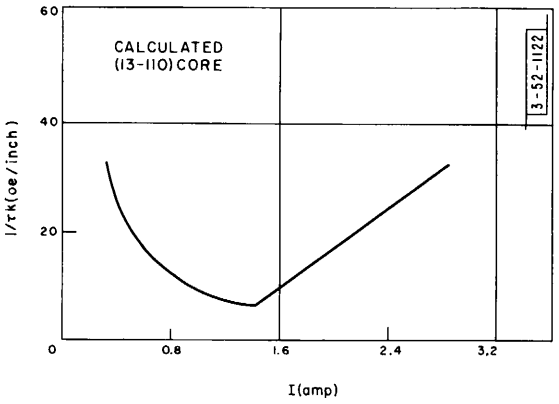


Fig. 52-2. Calculated core.

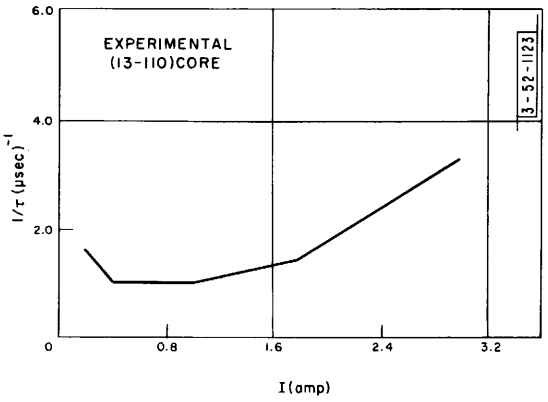


Fig. 52-3. Experimental core.

To investigate further which portion of the core is switching under partial switching conditions, a number of special cores were made having small holes at various points within the core so the flux changes from a given small hole could be sensed. Since these are large cores ($\frac{1}{4}$ inch in diameter) the field varies considerably from the inner hole to the outer edge. The cores were tested under conditions of very low field intensity so that the entire core did not have sufficient drive to switch. The portion of the core that switched agreed well with that predicted from the equation. The switching characteristic of this core is shown in Fig. 52-3. Calculations and tests were also made for high drive-current amplitudes but with short pulse-widths. The experimental results from this test do not agree as well as the case with low currents. Some error is due to the experimental measurements, since it is very difficult to generate a 2-amp current pulse lasting for less than 0.050μsec.

In addition to the above phases of the magnetics work, a study is continuing on investigating cores of materials other than that being assembled into the Group 47 memory. Little effort has previously been spent in studying the applicability of various available materials to impulse switched core memory. Many core materials have similar characteristics to those being used in the memory. It was found that low coercive force materials switched very slowly even with drive fields 30 times the coercive force, and the selection properties during a write cycle produce poor signal-to-noise ratios. Thus they have little use for standard memory purposes, but they have other special applications due to their ability to discriminate between currents of different widths; for example, they could be used for a nondestructive memory, although such a memory might not necessarily be fast.

R.H. Tancrell

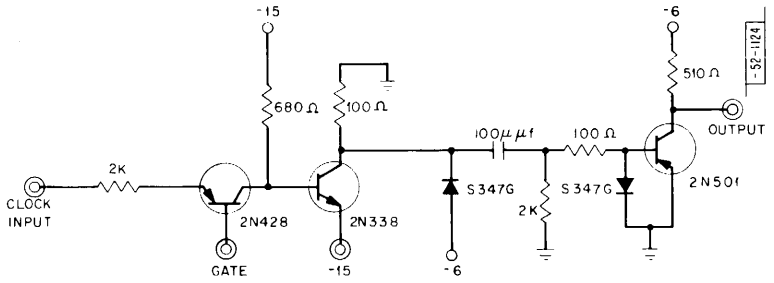


Fig. 52-4. Gated pulse amplifier.

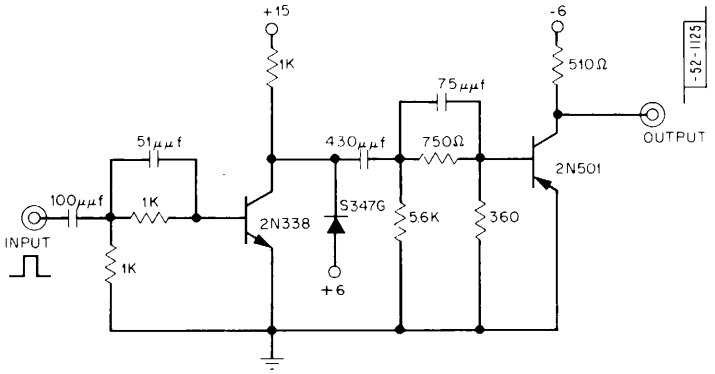


Fig. 52-5. Pulse amplifier circuit.

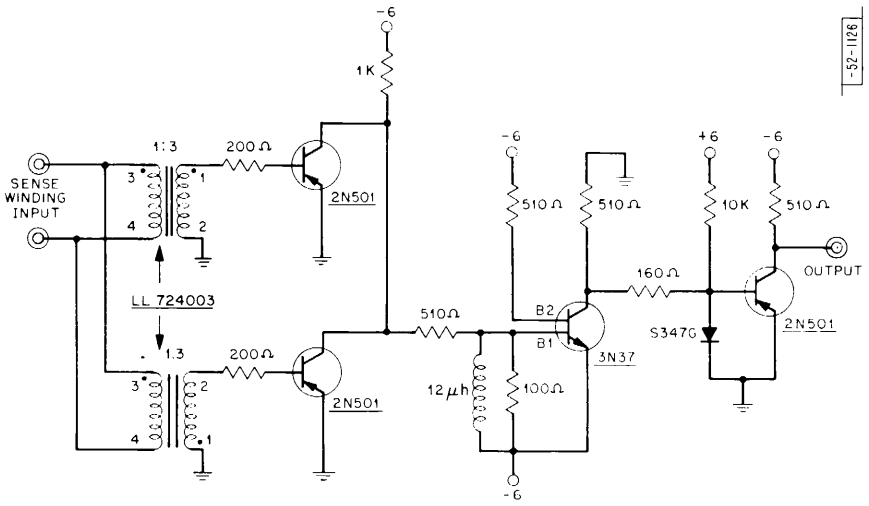


Fig. 52-6. Sense amplifier.

C. High-Speed Memory

A ferrite core memory that utilizes impulse switching techniques is under development for use in an advanced radar system. The memory will consist of 1040 words of 80-bit length and will have a sequential-access, linear-selection organization. The access time between words will be less than 1 μsec.

Several new circuit designs for the memory were completed during the past quarter. At this point the major design of the memory circuitry is complete.

1. Gated Pulse Amplifier

This circuit (Fig. 52-4) is used to set up the memory input register by means of a clock pulse gated by the memory input information. This information is simulated at present by various stages of the serial clock counter. Both the clock pulse and the gating level are clamped between 0 and −6 volts and the clock is enabled only when the gate is low (−6 volts). This is a system of negative logic that is consistent with the operation of the input gates on the high-speed gated flip-flop. The output pulse is clamped between 0 and −6 volts and is of the order of 0.15 μsec in width.

2. Pulse Amplifier

The pulse amplifier circuit (Fig. 52-5) is used to reconstitute degraded pulse waveforms and to provide reasonable pulse current drive capability. The output pulses are clamped between 0 and −6 volts and the base width is largely a function of the input pulse base width for relatively narrow pulses (up to 0.3 μsec).

3. Sense Amplifier

The sense winding on the core modules is wound in a bipolar fashion, thereby necessitating a differential input amplifier. The excellent gain-bandwidth capabilities of the 2N501, even at low levels, permitted the use of a very simple input stage for the sense amplifier (Fig. 52-6). Because of the mode of switching used, the read outputs from the core are of the order of 150 mvolts in amplitude and approximately 0.1 μsec wide, whereas the write outputs are about 80 mvolts and about 0.15 μsec wide. By using a pulse transformer input with a stepup turn ratio of 3, an effective clip level of about 60 mvolts is established, since the transistor has a gain threshold of the order of 180 mvolts. Read and write outputs are amplified in either one of the input transistors according to the pulse polarities. A 100-Mcps tetrode transistor (3N37) is used for the second stage inverter-amplifier and an inductor is used between emitter and base to shape the pulse, to provide fast turnoff and to control the storage time that might otherwise cause recovery problems in the amplifier. The final stage of the amplifier is a 2N501 which provides clamped positive pulses between 0 and −6 volts.

4. Shift Clock Generator

The operation of the sequential selection scheme depends quite heavily upon the shift clock driver. This driver must supply between 2- and 3-amp turns of pulse current excitation to the switch core line at the sequential address rate of the word drivers. Since there are 5 turns on the shift winding of the switch core, this requires about $\frac{1}{2}$-amp pulses at repetition rates in excess of 1 Mcps. Furthermore, the pulses must be narrow and have fast rise and fall times. Although these requirements in themselves are extremely difficult to meet with transistors, the problem is further complicated by the fact that these fast transition times generate very large inductive reverse voltages when driving the string of multiturn switch core windings. The addition of more word drivers does not result in a linear increase of the reverse voltage since the

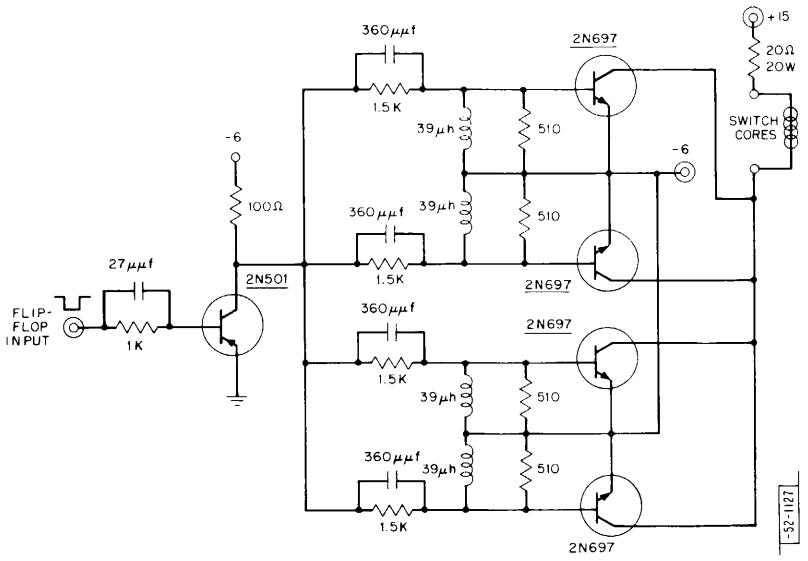


Fig. 52-7. Shift clock generator.

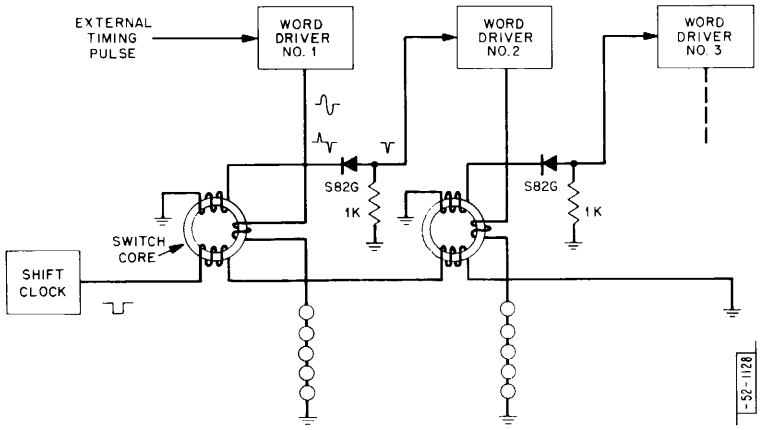


Fig. 52-8. Sequential selection scheme.

drive current rise time is degenerated by the higher reverse voltage because the transistors cease to become true current sources. This, in turn, reduces the amplitude of the switch core output and therefore begins to make the driver triggering pulse more marginal. An experimental memory has been operated with 30 word drivers and has exhibited good margins. Extrapolating from this point, 100 words appear to be a practical limit for one driver (assuming overshoot damping techniques). This would require one shift clock driver for each memory assembly (a total of 10) and is certainly an acceptable solution.

The shift clock generator (Fig. 52-7) is a brute force parallel buffer using medium power, high-gain-bandwidth transistors (2N697). Inductor pulse shaping is employed on all of the driver transistors to reduce the probability of thermal runaway (discussed in the Division 3 Quarterly Progress Report for 15 July 1958 under Sec. D – High Speed Memory) and to control storage and fall time durations. The input may be supplied directly from a high-speed set-reset flip-flop thereby allowing the timing of the shift clock to be accurately controlled by low-level pulse delay circuitry.

The current pulse output of this driver must be quite narrow because of the nature of the sequential selection scheme (Fig. 52-8). The switch core associated with a particular driver is first set by a read current pulse from that driver (which, for the first driver, is triggered by an external timing pulse) in one stable state. The write overshoot excitation by itself however, is insufficient to return the switch core to the other stable state as is the case with memory cores. Thereafter, the application of a shift clock excitation opposed to the read excitation is sufficient to switch the core. The pulse output from the core is then used to trigger the adjacent word driver, whereupon the action is repeated in the switch core in the adajacent driver line. As is the case with any shift register scheme, some delay is required to accomplish it. The delay in this case is inherent in both the switching time of the core and the triggering mechanism of the p-n-p-n driver. However, this delay can have a minimum value of 0.1 μsec for some driver circuits and 0.1 μsec for the cores. Therefore, if the shift current duration exceeds about 0.25 μsec, the read current excitation is reduced by the shift current excitation still present and the switch core cannot be set up. Experience with the memory system so far indicates critical operation of the selection scheme for widths above 0.25 μsec. The present driver is capable of holding this width for $\frac{1}{2}$-amp currents. But efforts are continually exerted to evaluate more capable transistors to fill the stringent requirements of this driver, since it is the only part of the system which will not meet the ±20 per cent voltage margins characteristic of the other circuit designs.

5. Sense Amplifier Gating

Because of the bipolar sense winding arrangement, it will be necessary to separate the read output from the write output. The conventional method of strobing for coincident current ferrite core memories is to generate a narrow clock pulse at the time a peak output from the core is expected, and to form a logical "and" circuit consisting of the clock and the sense amplifier output. However, upon examination of the possible outputs from a particular core in a given cycle time, we find that the following four possibilities exist:

(a) Read "one" write "zero" (R1, W0)
(b) Read "one" write "one" (R1, W1)
(c) Read "zero" write "zero" (R0, W0)
(d) Read "zero" write "one" (R0, W1).

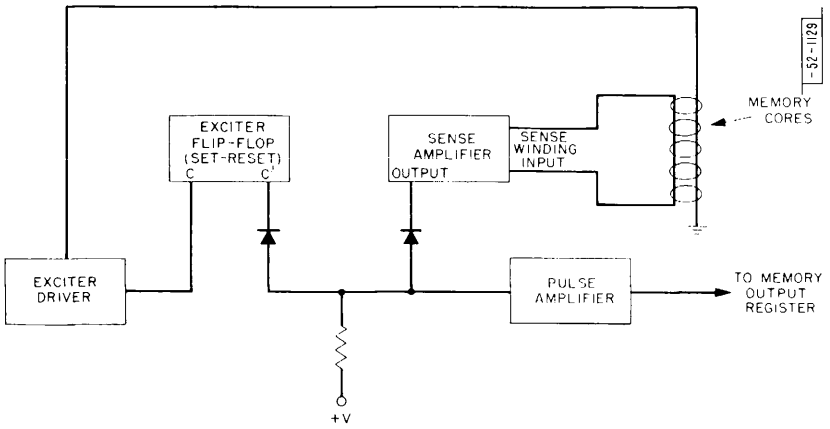
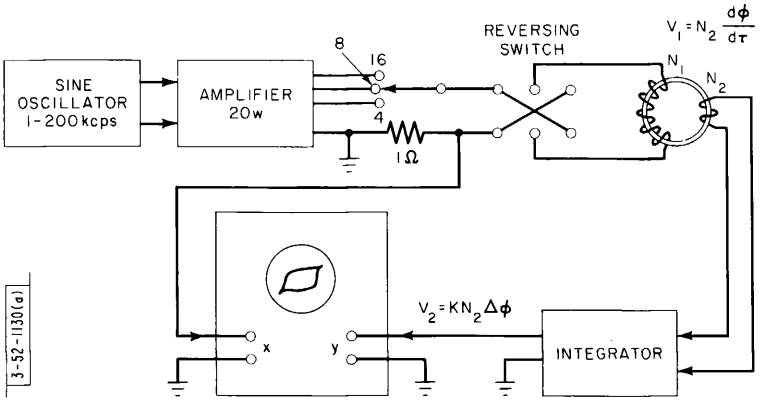
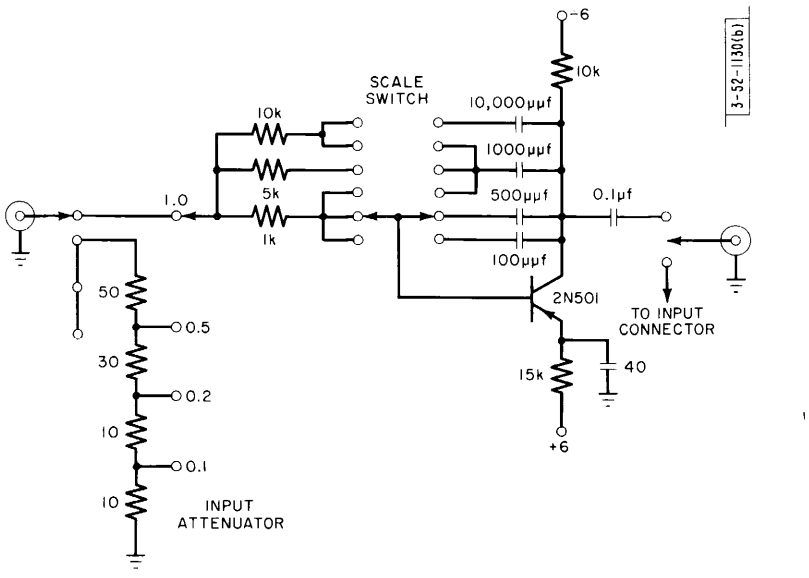


Fig. 52-9. Sense amplifier strobe logic.



(a) Block diagram of the plotter.



(b) Integrator circuit.

Fig. 10. High-frequency hysteresis loop plotter.

If these outputs were applied directly to the output register (on the set input of the set-reset flip-flop) only sequence (d) would cause a false output since the output register is intended to signify the state of the read output and not the write output. If we carry the examination of the logic one step further, we find that sequence (d) can exist only when the exciter driver has been turned on to write a "one." Since the exciter driver is a high current buffer driven by one side of a set-reset flip-flop, we have available the logical complement of the exciter waveform. Furthermore, since the flip-flop gate schemes employ negative logic, and since both the sense amplifier and flip-flop outputs are clamped between 0 and −6 volts, it is possible to use a simple "and" circuit configuration with high-speed diodes to inhibit the output of the sense amplifier during the time that the exciter is turned on. In cases where the exciter is not turned on (when writing a "zero") the sense amplifier is not inhibited during write time but the noise levels when writing a "zero" are clipped by the sense amplifier and do not appear in the output. Figure 52-9 is a logical diagram of the new scheme.

This new strobe (or gating) method is quite general and may be applied to any memory system where noise is not expected to appear at the sense amplifier output during write time. Its principal advantages over the conventional strobing method is its logical simplicity and its wider tolerance to system time delays.

6. Small Memory System

The small test memory described in the Group 32 Quarterly Progress Report for 15 October 1958 was successfully operated at sequential access times of about 0.9 μsec. This memory consisted of 30 words (10 more than originally proposed) of 15-bit length. However, in one of the word lines, 65 more bits were added and all 80 bits were made "ones" and "zeros" alternately with no appreciable change in the drive currents resulting between the two loads. The 0.9-μsec minimum sequential access time resulted from the inability of the shift clock generator to maintain adequate margins at such high repetition rates. Much of the continuing circuit work on the memory lies in the area of improving this single driver circuit.

7. Final Memory System

Much of the hardware for the final memory system is "in the works." Power supplies have been ordered, two cabinets have been constructed and power and air distribution systems are being installed, printed circuit boards of all circuits have been ordered from the wiring shop, memory arrays are being assembled in final form, and component procurement for the over-all system is nearing completion. A good portion of the following quarter will be spent in putting the finished pieces of the system together and in tying up remaining details of the small memory while using it to investigate anticipated system problems.

V. J. Sferrino

D. High-Frequency Hysteresis Loop Plotter

A piece of test equipment was designed and constructed to plot B-H loops at frequencies of 1 to 200 kcps. Figure 52-10(a) is a block diagram of the system. A sine wave oscillator drives an amplifier capable of several amperes current output. The output stage uses pentodes for high internal impedance, to minimize the effect of reverse voltage upon drive current. An impedance selector switch is provided to allow a compromise between high current output and high internal impedance. The current that drives the core is sampled by a one-ohm resistor, the voltage being applied to the horizontal input of a scope.

The sense winding of the core provides a voltage

$$V_1 = N_2 \frac{d\varphi}{dt} \quad .$$

An integrator is used to provide a voltage V_2 proportional to flux change. Thus

$$V_2 = K \int_{\varphi_1}^{\varphi_2} V_1 = K \int_{\varphi_1}^{\varphi_2} N_2 \frac{d\varphi}{dt}\, dt = KN_2\Delta\varphi \quad ,$$

where K is a proportionality constant, with units of volts per weber.

Figure 52-10(b) is the circuit of the integrator. A Miller circuit is used, with a switch to select various time constants of the integrating resistor and capacitor. Large time constants allow tests at low frequencies, but the proportionality constant K is reduced. (K is approximately equal to 1/RC volts/weber.) This can result in unusably small outputs in the case of small cores. The selection switch allows a compromise to be reached for each test.

The output of the integrator is applied to the vertical input of the x-y scope, to provide the plot of flux change against drive current. Conversion constants depending upon the core dimensions may be used to obtain B vs H.

D. B. Eshleman

III. COMPUTER DESIGN

Since the completion of the design of CG 24, some effort has been devoted to the study of more advanced computing systems. These studies have been motivated by two considerations. The first of these stems directly from work on the design of the CG 24 control.[1] The latter is essentially a diode memory, each word of which represents a "state" of the machine. Theoretically the nature of CG 24 can be altered by changing the contents of this control memory, i.e., by "programming" the control of the machine. Practically speaking, however, the structure of the rest of the machine allows only a relatively small degree of variability. It is therefore of interest to investigate computer structures with a higher degree of flexibility. The second motivation is the desirability of considering the design of large parallel-type computing systems or systems of interacting computers. Both of these objectives are being studied from the point of view of communication within digital systems or equivalently from the point of view of how information is transferred from one place to another in the system.

The lowest level of interaction within a computer is the transfer of information from one register to another. If the concepts of register and transfer are generalized to include conditional transfers of information between pairs of registers, we obtain a simple method of considering the basic interactions of a computer.[1,2] Any digital system is essentially a collection of such generalized registers. These registers are usually grouped together in sets. Hence, any system can be considered as some configuration of these sets of registers. The interactions within a computer can then be grouped into two classes: (1) interactions within each set of registers and (2) interactions among sets of registers. Complex systems of computers may be treated in a similar fashion by considering: (1) interactions within each computer and (2) interactions among the computers.

I. L. Lebow

IV. DIGITAL DISPLAY

A transistorized, digital, cathode-ray-tube display is under development. This device will have the following features:

(a) A 12-inch, magnetic focus and deflection, high resolution (between 1000 and 2000 lines) tube will be used.

(b) X-Y spot positioning will be by means of high current transistor switches driving a very low inductance (12μh) deflection coil (8-amp full deflection current).

(c) Spot settling time will be about 20μsec.

(d) The goal is a spot size of 0.01 inch or less with a beam current of 50μamp or more.

(e) Alphabetic, numeric and other symbols will be generated on the tube face by spot writing. The scheme to be used is a generalized Lissajous pattern technique and is described in Lincoln Laboratory Memorandum No. 2G-24-76. The rate will be 20,000 characters per second.

This equipment has been constructed; testing and modification are now in progress.

E.J. Aho
K.E. Perry

V. COMPUTER CIRCUITS

A program to develop high-speed computer circuits has been initiated. The goal of this program is to develop a series of computer circuit components that operate at a clock rate of ten megapulses per second. At this frequency, the "pulse-no pulse" representation of binary numbers offers some advantages over the DC level representation. These include:

(a) Less power required,

(b) Fewer power supply voltages,

(c) Simpler circuits,

(d) Easier transmission of signals (via pulse transformers).

The work to date has therefore been on the "pulse-no pulse" representation. In a system using this representation, a "one" is represented by a pulse and a "zero" is represented by the absence of a pulse.

One of the problems at high pulse rates is the lack of commercial test equipment. Early efforts were therefore devoted to the design of clock pulse generators. A number of circuits were tried. One of the more successful designs is shown in Fig. 52-11. The inputs to the circuit are two sine waves with a relative phase of $180° \pm \varphi$. These are squared and added to produce the output pulse. The width of the output pulse depends on φ.

A simple shift register circuit is shown in Fig. 52-12. The storage elements are capacitors, which are charged and discharged via transistors and diodes. The operation is as follows: Assume all capacitors to be charged so that their left plates are at -7 volts, and their right plates are at ground potential. Under these conditions assume a small negative pulse to be applied at the base of transistor T_1 at a time coincident with one of the B clock pulses. This will cause the collector of the first transistor to rise to ground potential. At the end of the pulse, capacitor C_1 will be charged so that both the left and right plates are at ground potential. These conditions will remain until the arrival of the next A clock pulse. At this time capacitor C_1 will be restored to its original charge. In the process, however, a small negative pulse is applied to the base of transistor T_2. This, in turn, will cause the left plate of capacitor C_2 to rise to ground potential. The arrival of the next B clock pulse will restore capacitor C_2 to its original charge, and propagate the pulse to the next stage. And so on. If no pulses are applied to the base of transistor T_1, no pulse will be propagated. The circuit is therefore capable of propagating any pattern of "pulse" and "no pulse" introduced at the base of transistor T_1.

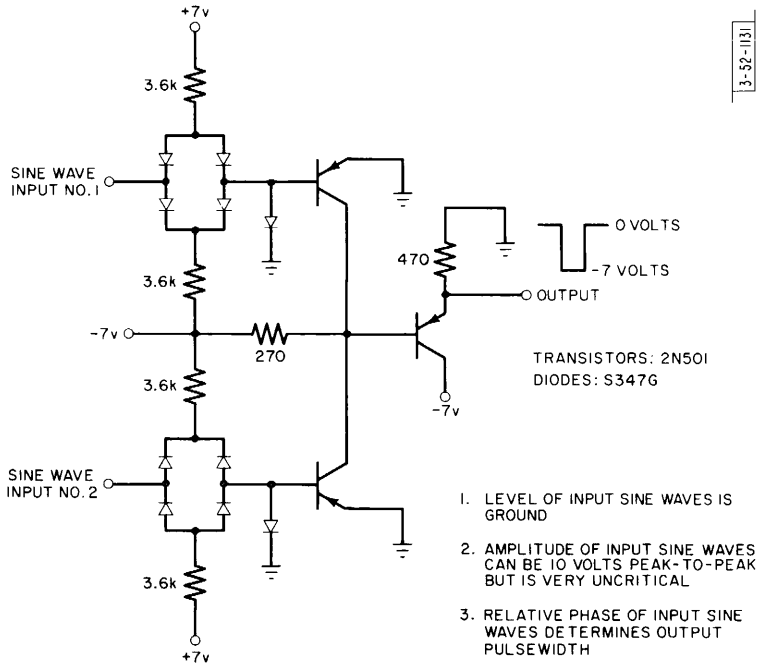


Fig. 52-11. Pulse generator.

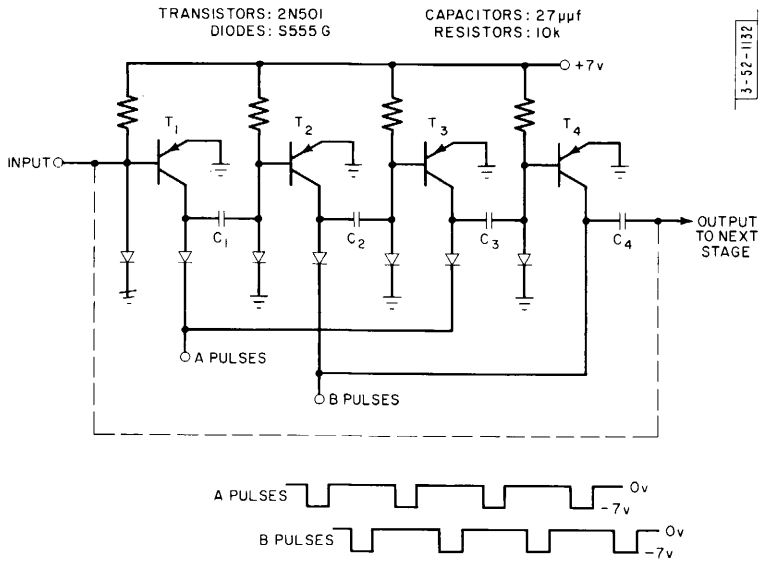


Fig. 52-12. Capacitor shift register.

If the shift register has an even number of stages, the output can be connected to the input to form a recirculating loop. This connection is shown by the dotted line in Fig. 52-12. Pulse patterns can then be stored indefinitely.

As clock rates are increased into the megapulse range, grounding problems become more difficult and relatively long transmission distances become harder to achieve. One way of combating this difficulty is to employ pulse transformers. A high-frequency pulse transformer based on a technique described in a translation of a Russian journal has been developed.[3] In this construction, two toroidal cores are used. The primary winding is wound on one core, and the secondary winding on the other. The two toroids are enclosed in a brass shell. A screw is passed through the toroids and connected at each end to the shell. The two toroids are thus linked by a single turn made up of the screw and the surrounding brass shell. A thin brass shim connected to the shell, but not to the screw, is placed between the toroids to provide electrostatic shielding. A sketch of this construction is shown in Fig. 52-13. For simplicity the windings are not shown.

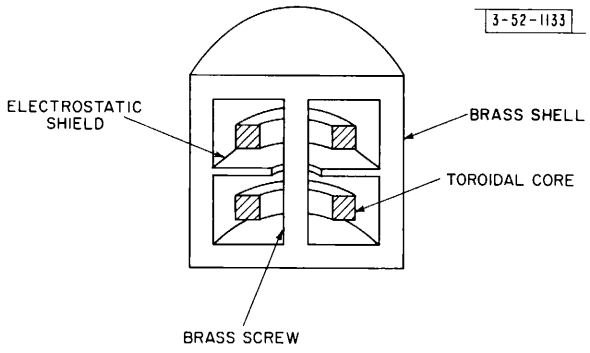


Fig. 52-13. Section showing pulse transformer assembly.

Several transformers have been constructed by this method. Their main advantages include ease of manufacture and low capacitive coupling between primary and secondary toroids. This means that the same transformer is equally good in inverting or noninverting use. Also, good isolation can be obtained. A feature of these transformers, which makes them especially attractive for experimental work, is the ease with which the turns ratio can be varied. To accomplish this, only the primary toroid or the secondary toroid need be replaced. A stock of n toroids, each with a different number of turns will yield $(n^2 - n)/2$ possible turn ratios.

In addition, designs have been obtained for "and" and "or" circuits, compatible with the shift register. One of the more difficult tasks has been the design of an inverter. Work on this circuit is in progress at the present time.

R. W. Hofheimer

VI. DIGITAL DATA TRANSMISSION

The Laboratory's program of research and development in digital data transmission consists of three parallel and closely related efforts. Figure 52-14 shows a typical communication channel. The messages are encoded into symbols, usually a string of binary bits that are then passed on to the transmitter. The transmitter-receiver pair perform the necessary modulation and demodulation of the symbols into signals, usually pulses or waveforms, which are carried

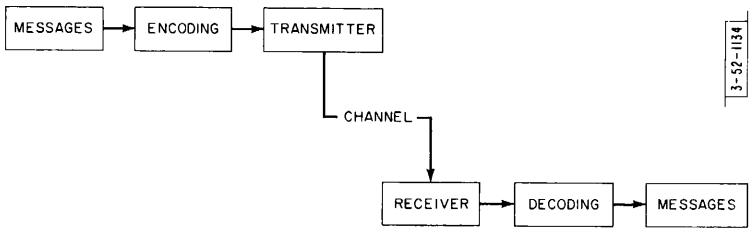


Fig. 52-14. Communication channel.

by the channel. Finally the symbols are decoded into the message format. The measurement of the channel statistics leading to the determination of the kind and frequency of errors and the investigation of new methods of waveform generation are two of the programs of the Laboratory. These will be reported, respectively, in Quarterly Progress Reports for Division 2 and Division 3. Our program is concerned with the methods of encoding and decoding messages with particular emphasis on the problem of providing error detection and error correction.

Beginning with the classical work of C.E. Shannon,[4] there have been many investigations[5,6] of coding schemes which add redundancy to messages for the purpose of detecting and correcting errors. Although Group 52 has had a broad interest in information theory, primary effort has been placed on the development of codes that are simple to construct. Nearly all of the published work on codes is concerned with block codes. By a block code is meant a code that encodes a block of, say, m bits into a block of n bits, where the length of both blocks remains fixed.

A conceptually simple block code is one that uses a code book for coding and decoding. For example, the following code book

Message	Coded Message
00	000000
01	000111
10	111000
11	111111

codes the four 2-bit messages into four 6-bit messages. Redundancy is introduced in such a way that the coded messages have a minimum Hamming distance of three. The Hamming distance between two coded messages is the number of bit positions in which they differ. For example, the pair 000000 and 000111 have a Hamming distance of three and the pair 000000 and 111111 have a Hamming distance of 6. The Hamming distance has a special significance for the binary symmetric channel with independent bit errors. A binary symmetric channel is a channel that transmits binary information, say "zeros" and "ones," such that the probability of error is the same for the "ones" and the "zeros." For the independent bit error case with p, the probability of error, much less than 0.5, the most likely occurrence in a block of n bits is that of no errors, the next most likely is a single error, the next most likely is a double error, and so on. The Hamming distance between the transmitted message and the received message is a measure of the number of binary errors that have occurred in the channel, thus the most likely Hamming distance between the transmitted message and the received message is zero, the next most likely is one, and so on.

The set of transmitted messages of length n is a subset of all possible messages of length n. In a good code these messages are chosen so that the Hamming distance between pairs is as large as possible. Then in the decoding scheme a received n-bit message is associated with the nearest, in the Hamming sense, of the possible n-bit transmitted messages.

It is clear that if the block length is large, then the code book becomes very large. For example, if we attempt to code 64-bit words, the number of entries in the code book is 2^{64}. The code book required at the receiving end is still larger. Thus there is a severe storage requirement, even for relatively short code lengths. Another problem is the choice of the code points themselves. For this example, if we agree to encode the 64 bits into messages of 128-bit length, then the problem is the choice of 2^{64} points in a set of 2^{128} points that have a large pairwise Hamming distance.

The construction of good codes has been discussed in the literature.[5,6] Group 52 is particularly interested in the class of Reed-Muller codes. An example of this code is described in the next section. This code substitutes a computation requirement for a large storage requirement, and furthermore it is a computation that is relatively easy to implement. The theory tells how to choose points that have a satisfactory pairwise Hamming distance and further provides the rules for decoding based on simple majority tests. In the next section a Reed-Muller code for messages of 64-bit length is described.

G. P. Dinneen

A. Error Correcting Coder

A device is being designed which will encode a digital message into a redundant form for transmission over a telephone line, or similar communication channel. A matching device (decoder) at the receiving end of the channel will restore the original digital message. The introduced redundancy enables the decoder to restore the original message when a small number of the transmitted digits are in error.

This device employs the Reed-Muller error correcting codes.[7] The coding method was chosen so that the encoder will accept an input word of 64 bits (or less). This is translated into a word 128 bits long. The decoder can restore the original 64-bit message if no more than 7 of the 128 bits are in error. These errors may be distributed in any way throughout the encoded word.

The process of encoding involves generating and summing the terms in the expression

$$f = g_0 x_1 x_2 x_3 \oplus g_1 x_1 x_2 x_4 \oplus g_2 x_1 x_2 x_5 \oplus \cdots \oplus g_{34} x_5 x_6 x_7$$
$$\oplus g_{35} x_1 x_2 \oplus g_{36} x_1 x_3 \oplus \cdots \oplus g_{55} x_6 x_7$$
$$\oplus g_{56} x_1 \oplus g_{57} x_2 \oplus \cdots \oplus g_{62} x_7 \oplus g_{63} \quad , \qquad (1)$$

where the summation is "exclusive or" ($A + B = A'B + AB'$). The coefficients g_i are the bits of the incoming message and the variables x_i are the outputs of a 7-stage binary counter

$$x_1 = 010101 \cdots$$

$$x_2 = 001100 \cdots \text{ etc.}$$

Thus f is a serial sequence of 128 bits ($2^7 = 128$)

$$f = f_0, f_1, f_2 \cdots, f_{127} \quad .$$

The general term for Eq. (1) is $g_i x_\alpha x_\beta x_\gamma$ where each x may be $x_1, x_2 \cdots, x_7$ or I (constant unity).

Figure 52-15 shows a block diagram of the encoding circuit. The input data enter serially at a 1-kcps rate and each bit is stored in flip-flop g_i for 1 msec. During this time the data in the 128-bit shift register cycle around once and the term $g_i x_\alpha x_\beta x_\gamma$ is added (half-add without carry) to the stored value. The Y-counter increments at a 1-kcps rate and provides an address to the control memory which, in turn, generates the proper subscripts α, β and γ. These address the selection matrix to select the proper X-counter outputs for each term of the summation. Thus when the entire 64 bits of the input word are read in, the translated 128-bit word is stored in the shift register. This word is parallel shifted to the output shift register and is then serial shifted to the output at a 2-kcps rate.

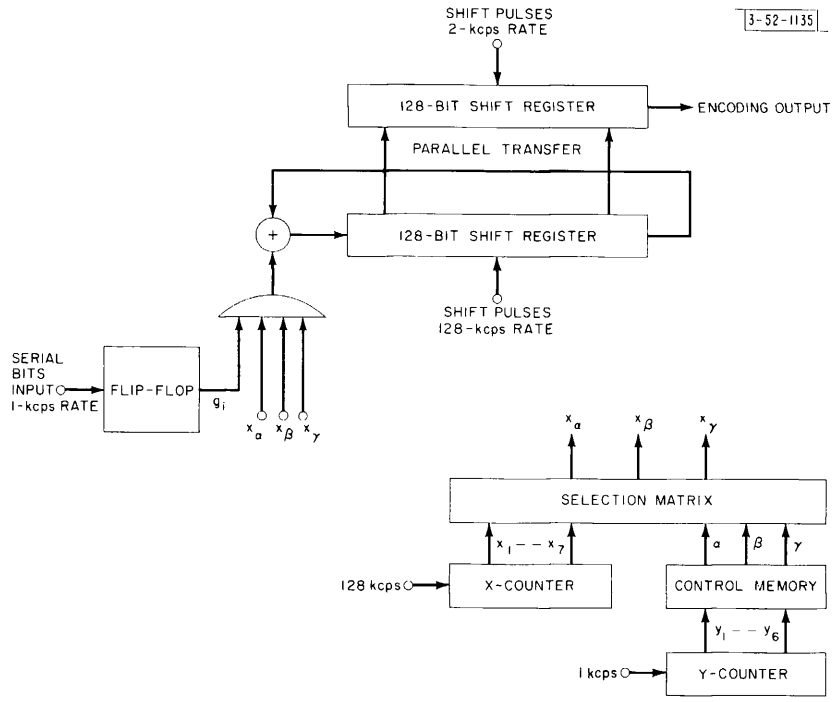


Fig. 52-15. Error correcting encoder.

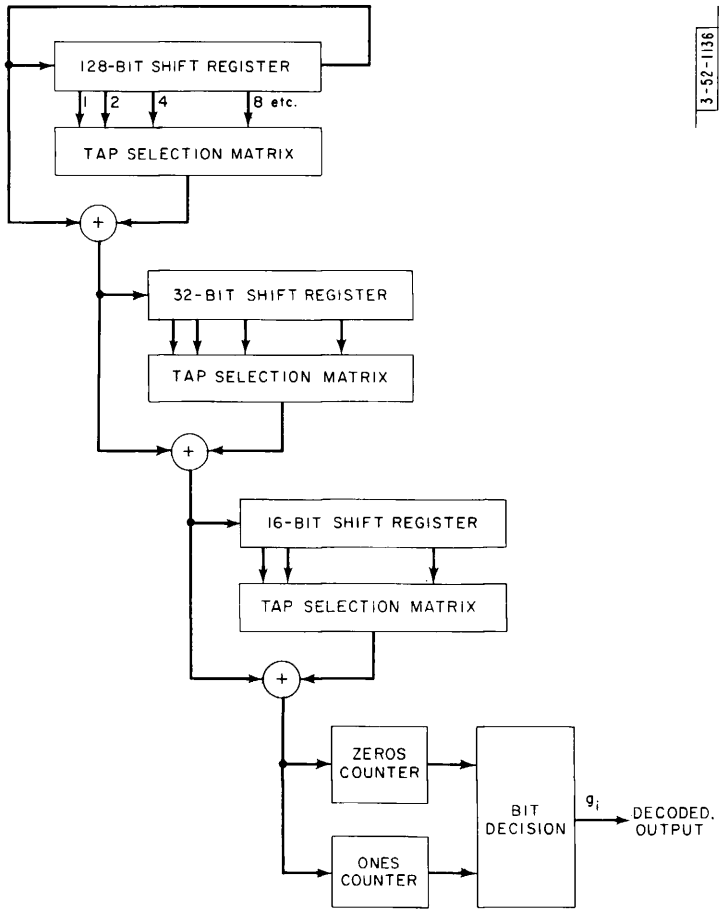


Fig. 52-16. Decoder shift registers.

Decoding the word at the decoder involves computing a number of parity relations for each output bit. For instance:

$$\left.\begin{aligned} g_0 &= f_0 \oplus f_1 \oplus f_2 \oplus f_3 \oplus f_4 \oplus f_5 \oplus f_6 \oplus f_7 \\ &= f_8 \oplus f_9 \oplus \cdots \oplus f_{15} \\ &\;\;\vdots \\ &= f_{120} \oplus \cdots \oplus f_{127} \end{aligned}\right\} \text{16 independent equations .}$$

To perform a circle sum on eight terms in one step requires a rather complex circuit so we break it up into simple steps involving two terms. If we examine all the equations for all the g_i-values, we find that the subscripts of the adjacent terms as we shall add them are always separated by powers of two (i.e., $f_0 \oplus f_1$, $f_0 \oplus f_4$, $f_2 \oplus f_6$, etc.). Thus we can assemble any desired pair of bits by having a 128-bit shift register with taps at stages 0, 1, 2, 4, 8, 16, 32, 64. Then by cycling the encoded word once around the register, every desired pair will appear at tap zero and one of the others at some time. The configuration of shift registers is shown in Fig. 52-16. Sums of bit pairs from one shift register are stored in the next shift register. Finally, out of the 16 bit shift register we receive the bit values of the 16 equations for g_i. These are counted in the zero and one counters and a majority decision on these two counters determines the value of g_i.

K.E. Perry

B. Error Correcting Code Circuits

Circuits are being designed for the error correcting code system. Figure 52-17 is the flip-flop to be used in the miniaturized shift register. Of these, 512 will be used in four

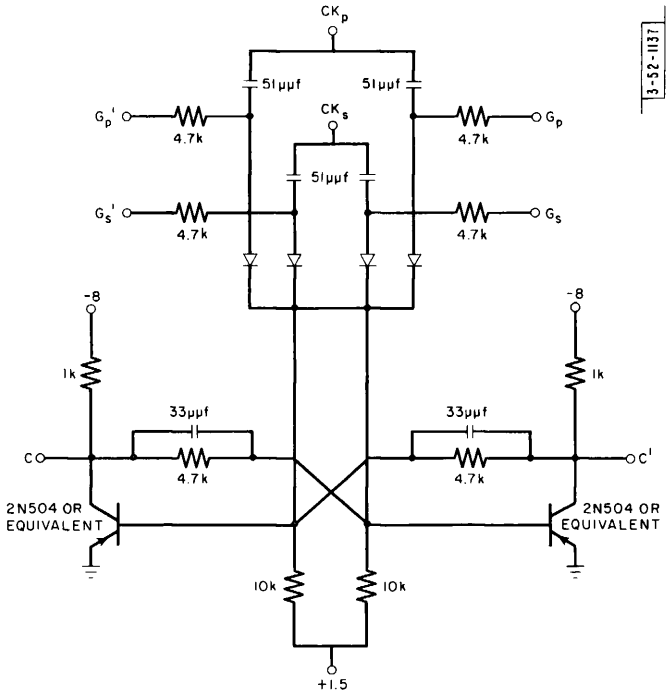


Fig. 52-17. ECCO shift register flip-flop.

128-bit shift registers. The positive input trigger may vary between two and eight volts. The supply voltages may be reduced to one-third the nominal with no effect other than reduction of output amplitude. The gates provide commutative operation up to 1.5 megapulses; the highest speed of operation in the system is 128 kcps. These wide margins are very desirable for the dependable operation of so large an array.

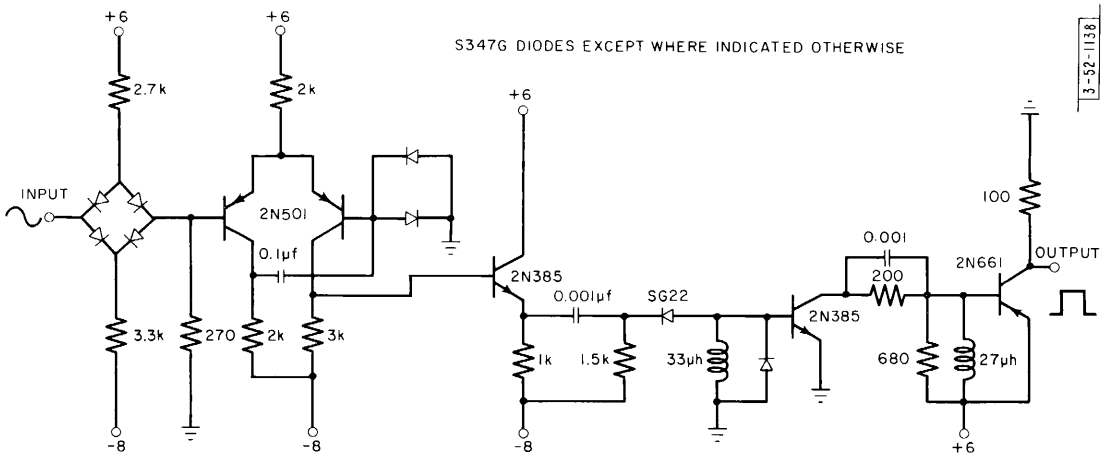


Fig. 52-18. ECCO clock generator.

The circuit shown in Fig. 52-18 takes sinusoidal timing signals from the telephone line or from a gated oscillator, and generates clock pulses for the shift registers. A Schmidt trigger provides a square wave, whose leading edge drives a pulse forming circuit. The output amplifier will provide 400 ma, which will be used to clock 128 flip-flops. This load may be split between parallel output stages if necessary.

D. B. Eshleman

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COMPUTER COMPONENTS
GROUP 53

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COMPUTER COMPONENTS
GROUP 53

I. GENERAL INTRODUCTION

The large, high-speed, general-purpose computers that are required by the military have placed a preliminary emphasis on bistable devices with the following characteristics: (1) reliability, (2) high speed, (3) assemblage of large numbers (low cost and high density), and (4) low power requirements.

Initial efforts to meet these requirements included the development of a magnetic material, operation specifications, and production procedures for a magnetic-core memory to replace the electrostatic storage tube originally installed in the Whirlwind I (WW I) computer. The resultant ferrite cores helped make possible the 4096 × 38-bit, 6-μsec cycle time memory first introduced into WW I, then into the AN/FSQ-7, and many commercial machines. Controlled production and testing procedures also made possible the ferrite cores for the 2.5×10^6-bit memory first introduced into TX-0 and TX-2, then retrofitted into the FSQ-7. Techniques were also developed for making and testing smaller (30 mil i.d., 50 mil o.d.) ferrite cores for use in transistor-driven core memories.

In the meantime fundamental investigations of the switching and loss mechanisms in ferrite toroids led to the conclusion that a much improved figure of merit for a magnetic memory component in a coincident-current memory could be obtained if the component consisted of an extremely thin disk instead of a toroid. With this geometry it should be possible to switch from one stable state to another via a simultaneous (rather than a sequential) rotation of the elementary atomic magnetic moments. With the aid of evaporation techniques, this geometry also offers the possibility of cheaper manufacturing, the preparation and testing of whole arrays replacing the testing and assemblage of individual units. Preliminary measurements proved switching times of $\tau < 20$ mμsec could be obtained in 83-17 nickel-iron films at reasonable driving currents currently used in ferrite-core memories.[1] A program was launched to develop production techniques that would permit the preparation of uniform arrays of elements that could be exploited for high-speed, random-access memories.

The logical element of principal interest has been the transistor. The transistor section has been engaged in four major activities: the study of the theory of transistors and other semiconductor devices as applied to switching circuits with a view toward improving device design; the evaluation of new devices as computer elements; the study of the degradation of semiconductor devices with operating life; and the incoming inspection and measurement of large numbers of transistors for computer use.

In 1954 it became apparent that the surface-barrier transistor (SBT) was suitable for high-speed computers and would be available in production quantities in the immediate future. Close liaison with the manufacturer enabled early development of transistor specifications for switching applications. A study of the nature of minority-carrier storage in surface-barrier structures led to suggestions for improvement of developmental microalloy transistors which are the basis for the present L-5134. The Lincoln Laboratory TX-0 and TX-2 machines have provided useful proving grounds for operation life tests on the various transistors used.[2,3]

As the TX-2, using these transistors in "5 megapulse" circuits, approaches completion, efforts are increasingly directed toward components that may permit an order-of-magnitude increase in circuit speeds. The start was an evaluation of the switching characteristics of

graded-base transistors.[4] Toward this end, three areas are currently being investigated: UHF transistors of the diffused-base variety, the parametron using either a varactor diode or a magnetic film, and the cryosar, a negative-resistance, low-temperature (4.2°K) device developed by Group 81. The cryotron, a low-temperature (4.2°K) superconductive element which shows promise of high-density packaging is also under investigation by Prof. Dudley Buck, the inventor of the device, at M.I.T. under a small subcontract.

The work in magnetic materials has been backed up by fundamental studies which attempt to define the relationships between engineering parameters on the one hand and the chemistry and physical state of the materials on the other. Such work requires a knowledge of the fundamental physical constants of the materials, much of which knowledge can be obtained only from careful measurements of the properties of single-crystal specimens of controlled chemistry. A small effort has been initiated to grow single crystals by the Bridgeman technique under elevated pressures of oxygen. The development of suitable ceramic techniques for production control has also led to interesting analytic techniques[5] and to preparation procedures for stoichiometric ferrites.[6] Historically, work was done to determine the factors that control the shape of the B-H loop (squareness, coercivity, B_s, . . .),[7] speed-power ratio for switching (figure of merit) in a coincident-current operation,[8] the noise,[9] Curie temperature, and the origin of the losses in ferrite toroids.[10] This led to the theoretical prediction of a fast rotational switch in magnetic films.

Blois [J. Appl. Phys. 26, 975 (1955)] had already demonstrated that deposition of Permalloy films in the presence of an applied magnetic field resulted in a uniaxial anisotropy that provided square hysteresis loops ideal for the memory application. Rotational switching was achieved experimentally by Olson, Pohm and Rubens (unpublished work reported at the Armour Symposium, 4 – 6 April 1956) by the simultaneous application of a reversing and a perpendicular field. However, the switching speeds obtained by these investigators were disappointing. At Lincoln Laboratory, belief in the possibility of a fast rotational switch led to high-speed instrumentation with the subsequent observation of 3-mμsec switching in a driving field of about 2 oe.[1] Other work on magnetic films has included a study of the correlation between transient switching and steady-state resonance,[11] the structure and properties of domain walls in Permalloy films,[12,13] the magnetic effects of the isotropic strain that is always present in evaporated films,[14] and the physical origins of the magnetic anisotropy which is a key parameter in memory operation.[15] A review article, which provides a background for those aspects of the magnetic properties of thin films that appear to be most significant to both science and engineering, has recently been prepared.[16]

In a search for the relationship between chemistry and the fundamental physical properties of ceramics, it was pointed out that the relative symmetry of the outer-electron wave functions and the near-neighbor configuration should be important in determining the cation distribution in spinels, indirect magnetic-exchange interactions, and martensitic phase changes due to $3d^4$ or $3d^9$ ions.[17] As a result of this work, several systems were investigated experimentally to determine the precise role of the $3d^4$ cation Mn^{3+} in the spinel lattice.[18,19] Further work on the indirect magnetic-exchange interactions[20] led to an experimental investigation of several perovskite-type systems,[21] and to an investigation of the antiferromagnetic anisotropy in rocksalt-type structures.[22] The symmetry considerations (crystalline fields) also led to the interpretation of the peculiar magnetic properties of the system $(La,Ca)CoO_{3+\lambda}$ (Ref. 23) and to a new approach to the band structure of the transition metals and their alloys.[24] These considerations promise to provide an understanding of the fundamental mechanisms responsible for

crystalline anisotropy. In the meantime a vibrating-coil magnetometer was constructed for fundamental magnetic measurements,[25] and several single-crystal studies[26] have provided information on crystalline anisotropy and loss mechanisms in ferrites. The search for magnetic materials in structures other than the spinel has led to the discovery of several magnetic perovskites and ferrimagnetism in the rocksalt-type system $Li_xNi_{1-x}O$ (Ref. 27).

II. MAGNETIC MATERIALS

A. Introduction

The significance of the relative symmetries of the outer-electron wave functions and the near-neighbor configuration for cations or atoms in a crystalline lattice continues to dominate both the theoretical and experimental considerations of the group. The original investigations in oxides were concerned primarily with cations that have four-or-more outer d-electrons: in the cubic spinel phase these atoms couple magnetically according to the Néel scheme, the distortions from cubic symmetry follow the predictions from crystalline-field theory, and the magnitude of the atomic moments can be interpreted by crystalline-field effects. However, the Néel coupling scheme frequently breaks down if cations with three-or-fewer outer d-electrons are present. An experimental investigation of the origin of the B-B interactions in spinels has therefore been initiated. The results of an investigation of the system $Ni_{1-x}Mn_{2+x}O_4$ for possible use as thermistors have also motivated this work. This latter investigation has definitely established the high-conductivity mechanism of the materials in this system. A series of orthoborates was prepared in order to investigate a new crystallographic structure for possible ferrimagnetic properties. The initial results indicate the presence of antiferromagnetism. Further progress on the band structure of the transition metals from the general perspective outlined above has not only led to refinements of a suggested approach to this problem, but also to the initiation of an experimental investigation of some interstitial-type alloys. A study of the magnetic properties of a natural single crystal of the tetragonal spinel Mn_3O_4 has been initiated with the hope of obtaining further insight into the origin of crystalline anisotropy and loss mechanisms in magnetic materials.

B. Inorganic Chemistry and Crystallography

1. Spinels Containing $3d^{3-n}$ Cations (n = 0, 1, 2)

The saturation magnetization values for a number of magnetic spinels, $A[B_2]O_4$, is adequately explained by assuming that the magnetic moments on the two sublattices A and B are oriented antiparallel to one another. This situation, as described by Néel, is the result of a preponderant negative indirect-exchange interaction between the moments on the two kinds of lattice sites. This explanation cannot be extended to all the magnetic spinels, and there is another group in which the AA or BB interactions are apparently comparable to the AB interactions. In this case the moment of one of the sublattices is not obtained by adding together the ionic moments present. Among the spinels studied up to the present time, those containing Cr^{3+} are the most notable in exhibiting unpredictable magnetic moments.

Trivalent chromium ions are known to occupy the octahedral sites of the spinel structure almost exclusively. The Cr^{3+} ion, with the outer electron configuration $3d^3$, is stabilized in the octahedral site because the $d_{x^2-y^2}$ and d_{z^2} orbitals (e_g), which are extended toward negative oxygen anions at the corners of the coordination octahedron, are empty. The d_{xy}, d_{yz} and d_{zx}

orbitals (t_{2g}) each contain one electron. Examination of the spinel structure shows that the t_{2g} orbitals of a Cr^{3+} ion are extended toward the t_{2g} orbitals of nearest-neighbor Cr^{3+} ions. It is conceivable, then, that the BB interactions are direct interactions that involve the electrons occupying the t_{2g} orbitals of neighboring Cr^{3+} ions. Since a lack of e_g electrons reduces the strength of the AB interactions (exchange via π rather than σ-bonding), the BB and AB interactions may be comparable. If this concept is correct, unpredictable magnetic moments possibly will be observed for many spinels whose octahedral site cations have the outer electron configurations, $3d^1$, $3d^2$, $3d^3$ or (if tetragonal) $3d^4$. An effort is being made to prepare and study spinels containing the cations $V^{3+}(3d^2)$, $V^{4+}(3d^1)$, $Ti^{3+}(3d^1)$ and $Mn^{4+}(3d^3)$. Several such compounds are listed in Table 53-I. The magnetic moments that have been measured by N. Menyuk and K. Dwight with the vibrating-coil magnetometer (H = 10,000 oe, T = 4.2°C) are compared with values calculated for the simple, antiparallel coupling of A and B site moments (spin-only values). The preparation of compounds containing V^{4+} ions was described in the Quarterly Progress Report on Solid State Research for 15 January 1959.

D. Wickham

2. Orthoborates, $M_3^{2+}(BO_3)_2$

Several orthoborates have been prepared by heating together a mixture of the oxide MO ($M = Mn^{2+}$, Co^{2+}, Ni^{2+}, Mg^{2+}) and a slight excess of H_3BO_3 under the appropriate atmosphere. Several compositions in the solid solution series, $Ni_3(BO_3)_2 - Co_3(BO_3)_2$ and $Co_3(BO_3)_2 - Mg_3(BO_3)_2$ were prepared. The magnetization at 4.2°K in a field of 10,000 oe was

TABLE 53-I

MAGNETIZATION $n_B(\mu_B$/molecule, 10,000 oe, 4.2°K) OF SEVERAL SPINELS CONTAINING $3d^{3-n}$ CATIONS

Compound* $A[BB']O_4$	Calculated n_B† $A[BB']O_4$ →←←	Calculated n_B† $A[BB']O_4$ →←→	Observed n_B (μ_B)	Cubic Lattice (constant a_o in Å)
$Mn^{2+}[V^{3+}V^{3+}]O_4$	~0.6	–	0.23	–
$Fe^{2+}[V^{3+}V^{3+}]O_4$	~0	–	–	–
$Mn^{2+}[Mn^{2+}V^{4+}]O_4$	~1.4	~0.6	0.7 to 0.77	8.579
$Fe^{2+}[Fe^{2+}V^{4+}]O_4$	~1.0	~1.0	0.53	8.422
$Co^{2+}[Co^{2+}V^{4+}]O_4$	1.0 to 1.7	0.3 to 1.0	0.21	8.385
$Mn^{2+}[Ti^{3+}Ti^{3+}]O_4$	~2.6	–	–	–
$Fe^{2+}[Ti^{3+}Ti^{3+}]O_4$	~2.0	–	–	8.47

* Brackets enclose ions occupying octahedral sites.

† See text.

measured by K. Dwight and N. Menyuk with the vibrating-coil magnetometer and found to be very small, n_B equal to 0.07 to 0.14 μ_B/molecule for the various pure materials. The value of n_B in the solid solution series, $Ni_3(BO_3)_2 - Co_3(BO_3)_2$ varies linearly with composition. The substitution of Mg^{2+} for Co^{2+} in $Co_3(BO_3)_2$ causes an increase in magnetization which could be indicative of the occurrence of antiferromagnetism in these compounds.

D. Wickham

3. Transition-Metal Nitrides

An investigation has been started to study the magnetic properties of transition metal nitrides. These alloys have interstitial structures, possess metallic properties, and in most cases are ferromagnetic. This study will attempt to show the quantitative relationship between ferromagnetism and the type of metal-nonmetal bonding present in these compounds.

A series of nickel-iron nitrides of the formula-type $Fe_{4-x}Ni_xN$ where $x < 2.95$ have been prepared as follows: Mixed iron-nickel oxalates containing various ratios Ni:Fe were coprecipitated and decomposed thermally to oxides. The oxides were then reduced to the metallic state with hydrogen, and the latter nitrided with NH_3 at 375°C to 600°C, depending on the amount of nickel present. Each composition crystallized with the face-centered γ' iron nitride (Fe_4N) structure. The unit cell edges vary from 3.797 ± 0.001 Å for $Fe_4N_{0.96}$ to 3.755 Å for $Fe_{1.05}Ni_{2.95}N_{1.20}$.

Crystallographic and magnetic data for compounds belonging to the system $Fe_{4-x}Ni_xN$ are summarized in Table 53-II.

TABLE 53-II
DATA FOR COMPOUNDS OF THE SYSTEM $Fe_{4-x}Ni_xN$

Compound	Analysis		Unit Cell	n_B^*	Fe/(Fe + Ni)
	Per Cent N	Fe/Ni			
$Fe_4N_{0.96}$	11.14	–	a = 3.797 ± 0.001	1.87	1
$Fe_{2.97}N_{1.03}N_{1.11}$	6.41	2.9	3.784	1.75	0.743
$Fe_{2.69}Ni_{1.31}N_{1.16}$	6.73	2.05	3.782	1.54	0.673
$Fe_{1.96}Ni_{2.04}N_{1.19}$	6.80	0.96	3.773	1.25	0.49
$Fe_{1.68}Ni_{2.32}N_{1.16}$	6.66	0.72	3.768	1.11	0.42
$Fe_{1.05}Ni_{2.95}N_{1.20}$	6.74	0.36	3.755 ± 0.002	0.85	0.263
Fe_2N	11.14	–	a = 5.527 b = 4.826 c = 4.419	0.41	–
$Ni_3N_{1.16}$	8.45	–	a = 2.669 ± 0.001 c = 4.300 ± 0.001	0.1	–

* n_B = magnetic moment/metal atom in Bohr magnetons at 4.2°K in 10,000 oe.

Face-Centered-Cubic Cobalt:– An attempt was made to prepare Co_4N by nitriding fine cobalt powder with ammonia at 350°C. A compound was formed under these conditions which possessed a face-centered-cubic structure with $a_o = 3.559 Å$. Chemical analysis for cobalt and nitrogen showed that only a small amount of nitrogen was present in the compound that had the formula $CoN_{0.075}$. The magnetization in 10,000 oe at 4.2°K was equivalent to 1.37 Bohr magnetons/molecule.

A. Wold
R. Arnott

C. Ceramics

Compositions in the system $Ni_{1-x}Mn_{2+x}O_4$ ($NiMn_2O_4 - Mn_3O_4$) crystallize with the spinel structure, exhibit the properties of semiconductors, and are ferrimagnetic. The conductivity vs temperature characteristics have made these materials useful as thermistors. This fact, together with the group's interest in the magnetic and crystallographic properties of spinels containing trivalent manganese, stimulated an investigation of the system. An attempt was made to correlate the chemical constitution with the electrical conductivity, the magnetization, and the crystal symmetry. Information, as it accrued, has been given in preceding reports, notably in the Quarterly Progress Report on Solid State Research for 15 January 1959.

Synthesis:– Compositions $Ni_{1-x}Mn_{2+x}O_4$ were prepared by heating mixtures of NiO and Mn_2O_3 under an oxygen atmosphere at an appropriate temperature that was determined experimentally. Some details have been given in the Quarterly Progress Report on Solid State Research for 1 November 1958.

Crystallographic Properties:– Materials crystallize throughout the system with the spinel structure. The lattice possesses cubic symmetry for values of x in the range $0 \leqslant x \leqslant 0.42$. For $x > 0.42$, the lattice possesses tetragonal symmetry with a value for c/a that increases from 1.000 to 1.162. Tetragonal materials become cubic when heated, the phase-transition temperature increasing from below –190°C for x = 0.42 to 1160°C for x = 1.0.

Conductivity Measurements:– Specimens of single-phase materials of the predetermined, correct composition were pressed in the form of annular disks and fired to obtain a rigid, dense body for conductivity measurements. After firing, the surfaces were ground off and coated with silver. The direct-current electrical resistance of each specimen was measured as a function of temperature over the range from about 25° to 200°C. The results were correlated by the equation

$$\sigma = \sigma_o \exp\left[-\frac{E'_g}{2kT}\right] ,$$

where σ is the apparent DC conductivity, σ_o the apparent DC conductivity extrapolated to infinite temperature, E'_g an experimental constant, k is Boltzmann's constant, and T the absolute temperature. It was observed that the value of E'_g is almost independent of composition throughout the cubic region; it increases slowly for values of x from 0.42 to 0.9 and increases sharply in the range $0.9 \leqslant x \leqslant 1$ (Fig. 53-1).

Magnetization:– The magnetization was measured at 4.2°K in a field of 10,000 oe with the aid of the vibrating-coil magnetometer. Values for n_B (μ_B/molecule) vary with x in a way that is difficult to understand. There is, however, an inflection in the magnetization vs composition curve corresponding to the change in symmetry. All Mn^{3+}-containing spinels studied in the laboratory have shown a similar behavior.

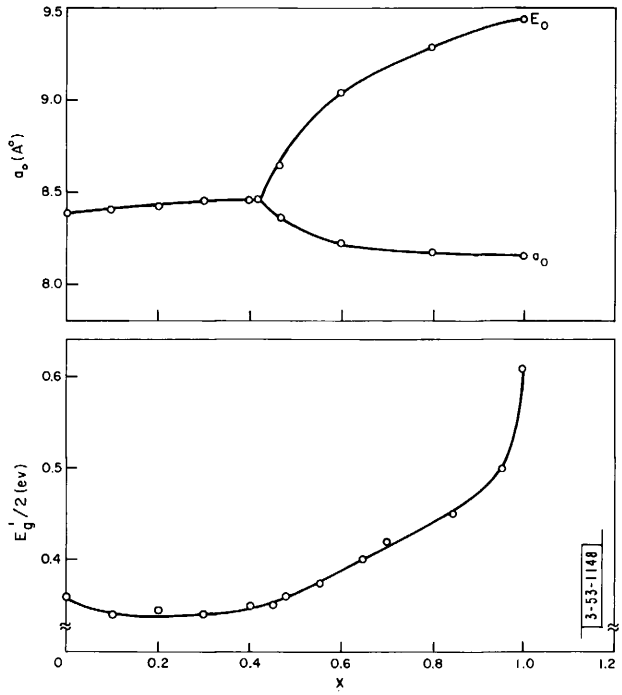


Fig. 53-1. Unit-cell dimensions (25°C) and activation energy for the system $Ni_{1-x}Mn_{2+x}O_4$.

Discussion:— On the basis of chemical intuition, one would expect $NiMn_2O_4$ (x = 0) to have one of the following structural formulas:

$$Ni^{2+}[Mn^{3+}Mn^{3+}]\,O_4 \qquad (1)$$

$$Mn^{3+}[Ni^{2+}Mn^{3+}]\,O_4 \qquad (2)$$

$$Mn^{2+}[Ni^{2+}Mn^{4+}]\,O_4 \qquad (3)$$

$$Mn^{2+}[Ni^{3+}Mn^{3+}]\,O_4 \quad . \qquad (4)$$

The neutron-diffraction studies reported by Azaroff[28] show that the Ni^{2+} is always in octahedral sites. These findings support those of Sinha, et al.[29] who came to the same conclusion on the basis of x-ray diffraction measurements. Therefore, formula (1) is ruled out. Formula (4) does not require serious consideration because pure $NiMn_2O_4$ is cubic and Ni^{3+} is seldom observed. The magnetic moment and Curie temperature studies of Baltzer[30] led to the conclusion that formula (3) is the correct one.

The appearance of tetragonal distortions in several spinel systems has been found to be associated with a critical composition of Mn^{3+} ions in the octahedral sites.[31] Compositions containing more than approximately 60 per cent of octahedral sites occupied by Mn^{3+} ions are tetragonal. If one considers the formulas (2) and (3), corresponding formulas for the system $Ni_{1-x}Mn_{2+x}O_4$ can be written

$$Mn_x^{2+}Mn_{1-x}^{3+}[Ni_{1-x}^{2+}Mn_{1+x}^{3+}]\,O_4 \qquad (5)$$

and

$$Mn^{2+}[Ni^{2+}_{1-x}Mn^{3+}_{2x}Mn^{4+}_{1-x}]\,O_4 \quad , \qquad (6)$$

respectively. The critical composition in system (5) would correspond to a value of x equal to 0.2, in system (6) to a value of x equal to 0.6. The observed value of x for the appearance of a tetragonal distortion is 0.42 so that the proper compositional formula for the system is probably a mixture of (5) and (6). The ions Mn^{3+} and Mn^{4+} would be simultaneously present in compositions corresponding to values of x from 0 to almost 1.000. Verwey, et al.,[32] have given the following requirements for high electrical conductivity in the transition-element oxides: The material must contain two cations of the same element, with oxidation values differing by unity, situated in similar lattice sites. The activation energy for electrical conductivity is the energy required to lift an electron out of its bound state in the neighborhood of the M^{n+} ion into a state in which it is free to move into the neighborhood of the $M^{(n+1)+}$ ion. Such a situation is realized in the system $Ni_{1-x}Mn_{2+x}O_4$ if Mn^{3+} and Mn^{4+} are both present in the octahedral sites as postulated above. The activation energy observed is noted to change only slightly through most of the system (Fig. 53-1).

In order to check the validity of the assumption of a $Mn^{3+} - Mn^{4+}$ conductivity mechanism, a ceramic specimen of the cubic spinel $Li^{+}[Mn^{3+}Mn^{4+}]\,O_4$ was prepared. The value of E'_g calculated with the aid of the measured resistance-temperature characteristic was found to be close to that observed for the cubic materials in the system $Ni_{1-x}Mn_{2+x}O_4$.

The magnetization of samples in the system can be interpreted in a qualitative way using a formula between (5) and (6) if a certain amount of B-B antiferromagnetic coupling is assumed. The Mn^{4+} ion has the outer electronic structure $3d^3$ and possibly can couple antiparallel to the other B-site moments (Sec. II-B-1). This interpretation presently is somewhat arbitrary because the magnetic moment of pure $NiMn_2O_4$ has not been determined with certainty. Stoichiometric $NiMn_2O_4$ is difficult to prepare, and the observed magnetic moment appears to be very sensitive to an oxygen deficiency.

E. Larson

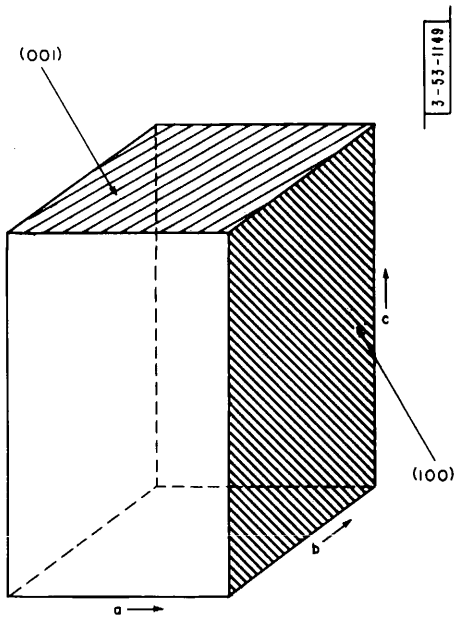


Fig. 53-2. Cube with tetragonal symmetry (a = b, c > a) showing planes of Mn_3O_4 crystal along which magnetic measurements were made.

D. Ferromagnetic Properties of Mn_3O_4

Recent measurements[18,33] have shown that hausmannite (Mn_3O_4) becomes ferromagnetic in the temperature range from 30° to 40°K. Hausmannite has a spinel structure with tetragonal symmetry[34] and an axial ratio c/a equal to 1.16 at room temperature. The tetragonality suggested to Goodenough and Loeb[17] that the ionic arrangement of cations in the spinel lattice is of the form $Mn^{2+}[Mn^{3+}Mn^{3+}]\,O_4$, where the cations in front of the brackets are on tetrahedral (A) sites, whereas those in the brackets are on the octahedral (B) sites. With antiferromagnetic A-B coupling and spin-only atomic moments, this leads to a predicted magnetic moment of 3 Bohr magnetons/molecule at 0°K. However, the moment of polycrystalline Mn_3O_4, as measured at 4.2°K (Refs. 33 and 34), has been found to be 1.4 to 1.6 Bohr magnetons. To explain this

discrepancy, Jacobs[34] has suggested that the reduced magnetization of Mn_3O_4 is due to a triangular arrangement of the atomic moments of the type first suggested by Yafet and Kittel.[35]

We have undertaken a study of the magnetic properties of a natural single crystal of hausmannite from Ilmenau, Thuringia. The samples are disks sliced along principal faces of the crystal.* The measurements thus far have been limited to a (100)-faced disk and an (001)-faced disk, as indicated in Fig. 53-2, and have all been made at 4.2°K.

1. Measurements on (100)-Faced Sample

Measurements made on the (100)-faced disk indicate that hausmannite is an extremely hard magnetic material. The maximum applied field available with the vibrating-coil magnetometer (12,000 gauss) is able to produce only slight rotation (~5°) of the magnetization from its easiest direction in the plane, and the anisotropy is uniaxial in the (100) plane. By measuring the deviation of the magnetization vector from the easy direction as a function of applied field direction, the value of the apparent uniaxial anisotropy field in this plane was found to be

$$K_{(100)} = 1.2 \pm 0.5 \times 10^7 \text{ ergs/cm}^3 \quad .$$

This value of the anisotropy constant corresponds to an anisotropy field (the field required to saturate the material in the hard direction) of 100 kilogauss (kG).

The M-H characteristics of hausmannite was studied in the (100) plane, and the resultant curve is shown in Fig. 53-3. The curve did not start at M = 0 because of the difficulty in demagnetizing the sample. The small remanence shown in the figure was found at 4.2°K after cooling the sample through the Curie point in zero field. The increasing magnetization with increasing field at the high-field end of the curve suggests that either the (100) is not the plane containing the easiest magnetization direction, or the magnitude of the angles in a triangular arrangement (or the number of reversed spins in antiferromagnetically coupled B sites) are susceptible to variation at these field strengths. The coercive force in this plane is approximately 3000 gauss. The magnetization is reversed by domain-wall motion and is an extremely slow process at these fields. The lines indicated by arrows represent the variation of M with time at a given field. We could not wait for the sample to come to equilibrium at the coercive field, since this would have taken on the order of an hour, which was longer than we could maintain the helium temperature. The numbers next to the various arrows signify the approximate time (in minutes) spent at each field to obtain the observed magnetization change. The long time required for the magnetization reversal suggests an extremely high relaxation frequency Λ. Further study of the dynamics of magnetization change in hausmannite is contemplated.

Finally, the magnetic moment along the easiest direction in the (100) plane was measured, and we found

$$\sigma_{A(100)} = 1.94 \text{ Bohr magnetons/molecule} \quad .$$

Furthermore, if the (100) plane does not contain the easiest direction of magnetization, the saturation moment could be larger. Although there appears to be a large discrepancy between these single-crystal results and the values of 1.4 to 1.6 μ_B obtained with polycrystalline samples, this discrepancy can be accounted for by the nearly uniaxial anisotropy of hausmannite. Indeed, in the limiting case of truly uniaxial symmetry and no rotation of the magnetization out of the easy

*We are indebted to J.W. Sanchez of Group 84 for x-ray orientation of the crystal.

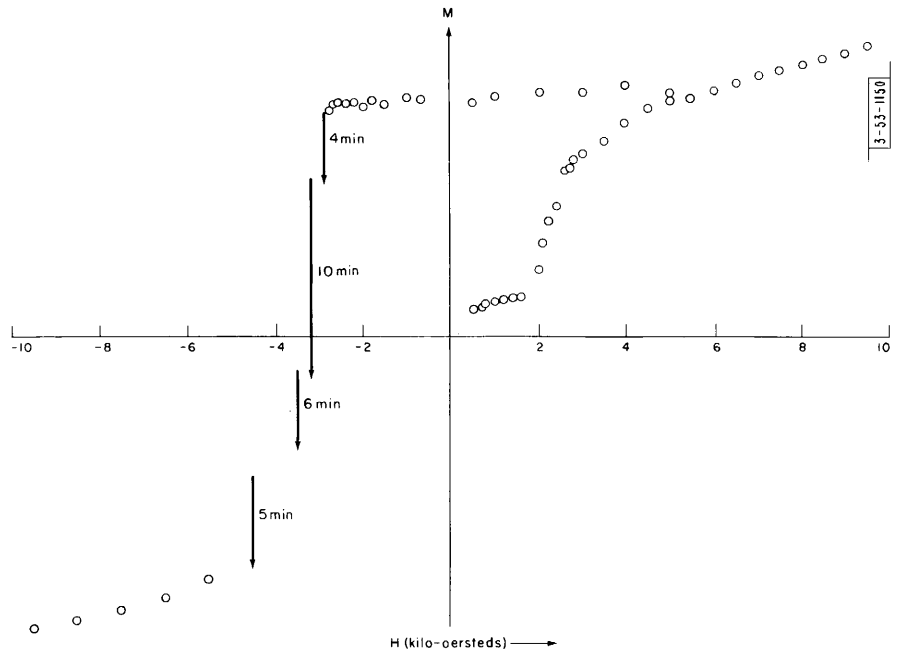


Fig. 53-3. Magnetization vs applied field along easiest direction in (100) plane of Mn_3O_4.

direction, the ratio of the saturation moment to that measured on a polycrystalline sample is 2:1. The application of this extreme correction factor to our polycrystalline measurement would raise its value from 1.4 to 2.8 μ_B.

The high anisotropy cannot explain the low moment obtained by Jacobs,[34] since his measurements were carried out at fields as high as 140 kG. However, these were pulsed fields, with a duration of approximately 28 msec (Ref. 36). The slowness of wall motion which we observed at low fields indicates that the pulselength may have been insufficient to permit saturation of the crystal.

2. Measurements on (001) Sample

Only preliminary measurements were made on the (001)-faced sample. If the c-axis were the easiest magnetization direction, there should have been little magnetization in the (001) plane with a 10-kG applied field in this plane. However, considerable moment was observed, which therefore eliminates the [001] as the easy direction. Furthermore, the anisotropy in this plane is also uniaxial, which corresponds to twofold magnetic symmetry. Since the crystal has fourfold crystal symmetry in this plane at room temperature, it is possible that a low-temperature transition temperature exists at which the crystal goes from a tetragonal to an orthorhombic structure. Various speculations about the nature of this unexpected effect are being held in abeyance pending further experimental investigations.

N. Menyuk
K. Dwight

E. Band Structure of the Transition Metals

Further consideration of the band structure of the transition metals has led to a modification of the original assumptions which is particularly relevant for b.c.c. iron. This reconsideration was forced by new data on the iron-cobalt alloys as well as by certain theoretical objections. The essential postulates of the present theory are the following:

(1) Half-or-less filled, directed atomic orbitals that strongly overlap corresponding near-neighbor orbitals form bands that consist of an occupied, bonding portion and an unoccupied, antibonding portion provided the near-neighbor configuration is such that antiferromagnetic coupling of bonded near neighbors can be propagated throughout the lattice.

Such bands are designated "bonding" bands since, in this situation, electrons on neighboring atoms need not exclude one another from the region midway between the positive cores. Whereas interatomic-exchange interactions would couple localized electrons antiferromagnetically, the strong near-neighbor perturbations delocalize the electrons in a manner analogous to covalent-bond formation. If localized electrons are present (d-electrons in next-near-neighbor-directed orbitals), they couple magnetically to bonding d-electrons via intra-atomic exchange: since the bonding band is basically antiferromagnetic, the localized electrons are coupled antiferromagnetically to bonded near neighbors (ferromagnetically to next-near neighbors). In this case the magnetic unit cell is larger than the chemical unit cell, and the bonding and antibonding portions of the band may be split by a discrete energy gap. Further, the presence of localized electrons should induce some localization of the bonding d-electrons to introduce a small, bonding-electron contribution to the atomic moment. If localized electrons are not present, the bonding electrons contribute only weak Pauli paramagnetism to the magnetism of the material. Further, the atoms are all identical and there is presumably no discrete energy gap between the occupied, bonding and the unoccupied, antibonding portion of the band; however, the density-of-states curve is expected to be bimodal with a deep minimum at the half-filled point.

(2) Outer, nonlocalized electrons in isotropic s-orbitals or in directed orbitals that do not fulfill the conditions for bonding-band formation occupy conventional metallic-type bands and metallic bands with a sufficient density of states (e.g., d-bands) may be spontaneously polarized by the exchange forces to give rise to ferromagnetism.

This is the conventional assumption of the band model. It should be noted, however, that filled atomic orbitals act as repulsive atomic cores so that any contribution of such a metallic band to the cohesive energy of a crystal must decrease with an increasing number of electrons in a nearly filled band. Also the Curie temperature is expected to vary with the magnitude of the polarization of the nonlocalized electrons in the polarizable metallic band. The observation of paramagnetic Pd with ~ 0.6 hole in the d-bands suggests the proviso that

(3) Spontaneous polarization of partially filled, metallic-type d-bands only occurs if a localized-electron atomic moment is present.

(4) If orbitals that are capable of forming bonding bands are more-than-half filled, only the antibonding portion of the band can be spontaneously polarized.

If the bands formed from overlapping near-neighbor orbitals are more-than-half filled, there are always some electrons that are excluded from the region midway between neighboring positive cores. Therefore, these electrons may be spontaneously polarized by the exchange forces without loss of binding of the two positive cores. However, spontaneous polarization of the entire band would withdraw negative charge from the region midway between the positive atomic cores: therefore, only the electrons in the antibonding portion of the band are polarized. These spontaneously polarized electrons render the lattice ferromagnetic, coupling atomic moments from localized d-electrons ferromagnetically via intra-atomic exchange. The maximum polarization of the antibonding portion of the band is half an electron per atomic orbital in the band: this occurs if the total band is three-fourths filled. As in the case of polarized metallic bands, the Curie temperature is expected to vary with the polarization of the antibonding band.

Consideration of the number of outer electrons and of the relative symmetries of the outer-electron wave functions and the near-neighbor configuration suggests a distinction be made between the band structures of b.c.c. metals with seven or less outer electrons (Ti, V, Cr, Mn; Zr, Nb, Mo; Ta, W) and those with more than seven (Fe, Fe-Co, Fe-Ni, Fe-Pt, . . .). The former group contain a less-than-half-filled bonding band and are therefore paramagnetic (no localized electrons) or antiferromagnetic (localized d-electrons present) whereas the latter group contain a band that is more-than-half-filled, yet meets the other requirements for bonding-band formation. In the f.c.c. metals the conditions for near-neighbor bonding-band formation are not fulfilled, and metallic-type bonding occurs. In the first long period of the Periodic Table the first holes in the d-bands are associated with localized d-electrons and spontaneous polarization of the bands takes place. In the second and third long periods, the first holes are associated with the metallic-type d-electrons so that the metals are paramagnetic. With $6 < n_d < 7$, the f.c. lattice becomes tetragonal ($c/a > 1$) and antiferromagnetic within (001) planes; with $5 < n_d < 6$ the f.c. lattice becomes tetragonal ($c/a < 1$) and antiferromagnetic between (001) planes. The first instance is believed illustrated by low-temperature f.c. iron, the second by low-temperature f.c. manganese. Other physical properties of the transition metals and their alloys are also consistently interpreted.

J. B. Goodenough

III. MAGNETIC FILMS

A. Introduction

During this past quarter considerable attention has been given to a new class of magnetic films: the so-called "inverted" films that have a wall-to-rotational coercive-force ratio $H_w/H_k > 1$ rather than the normal $H_w/H_k < 1$. The elimination of the competitive domain-wall process from the flux-reversal mechanism should provide a magnetic film that is much less sensitive to disturb signals. Films of this class which have been successfully prepared have several other anomalous characteristics, and attempts to unravel the cause of these anomalies is under way. A study of the effect of variation of the substrate temperature on film properties has also been started with the hope of developing a technique that may lead to better film uniformity. Investigation of the structure of films by the use of electron diffraction and electron microscopy has also been initiated, and preliminary results show the anticipated fiber axis perpendicular to the plane of the film. The use of a magnetic film in a variable inductor for use in a possible parametric computer element is also under investigation. Preliminary results indicate that operation with an X-band pumping frequency may be possible. The advantage over the reverse-biased semiconductor diode would lie in the mass-production possibilities associated with evaporation techniques.

B. Inverted Films

1. General Comments

Permalloy films deposited in a DC magnetic field exhibit a uniaxial anisotropy of the form $E_k = K \sin^2 \Theta$, where Θ is the angle between the magnetization M and the easy axis. The theoretical form of the consequent rotational hysteresis loops is well known and is shown in Fig. 53-4(a). Measured at 1000 cps, the predicted longitudinal loop is never observed, and reversal occurs by walls at a field $H_w < H_k = 2K/M$ [Fig. 53-4(b)]. Usually $H_w/H_k \sim 1/2$, although values approaching one are sometimes found. Since rotational switching is very fast compared with wall switching, it follows that at 1000 cps one should never observe the case $H_w/H_k > 1$,

since the film should always switch by rotation at H_k before the field H_w is attained. However, it is found experimentally that films prepared in special ways do exhibit $H_w/H_k > 1$ [Fig. 53-4(c)], where H_k is measured from the transverse permeability, and hence additional factors must be entering to cause a "locking" of the rotational state which prevents rotation at H_k. Films of this type are designated "inverted," referring to the behavior of the H_w/H_k ratio. For a given composition, the H_k of inverted films remains comparable to H_k in normal films, but H_w is raised.

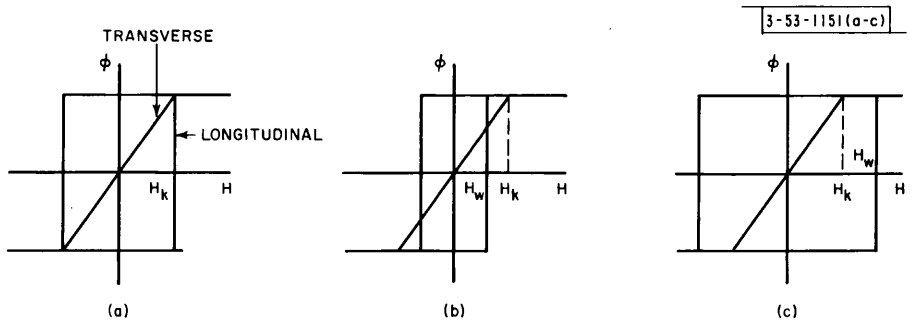


Fig. 53-4. Hysteresis loops for: (a) theoretical, (b) normal, and (c) inverted films.

2. Preparation

Inverted films can be made by a variety of methods that do not have obvious common characteristics. Three general methods are known: (a) slow evaporation (~1000 Å/hour) onto "normally" cleaned glass substrates;[37] (b) fast (~1000 Å/minute) or slow evaporation onto "specially" cleaned substrates;* (c) electrodeposition onto glass substrates that have an underlayer of sputtered silver when the sputtering voltage and pressure are held within certain limits.[38]

Normal substrate cleaning consists of washing in detergent (e.g., Alconox) and rinsing in distilled water agitated by ultrasound. If the detergent wash is followed by dipping in stannous chloride ($SnCl_2$) [Ref. 39] and then finally rinsed in distilled water, inverted films result. This is also the case if certain detergents (e.g., Aerosol) are used, omitting the $SnCl_2$ dip.

In considering what influence the above procedures might have on film structure, a connection is sought between the effects of slow evaporation rates and special cleaning. The cleaning that leads to inversion is intended to produce the cleanest possible substrate, which would consequently have a low density of growth nucleating centers present. Nucleation is also dependent on the rate of arrival of vapor atoms, since more atoms must arrive than leave by re-evaporation or surface migration in order for a growth nucleus to start. Thus it is suggested that the common feature in these two cases is the nucleation-center density. A more porous film could result if the nucleation density is low. The anomalous magnetic properties of inverted films will be shown to be qualitatively consistent with the idea of a film containing voids of a certain size. The films reported here are all ~1000 Å thick and near 83-17 in composition.

3. Bitter Pattern Studies

Insight into the nature of the locked state that must exist when $H_k < H < H_w$ is obtained from Bitter pattern studies. For H antiparallel to M in a film previously saturated in the easy direction, the pattern which appears is sketched in Fig. 53-5. Disconnected line segments, or striations, of colloid form perpendicular to H. This is interpreted as showing that M rotates

*A case of inverted films made by fast evaporation onto a glass substrate having a sputtered silver underlayer ~200 Å thick has also been observed by D. Strassberg, M.I.T. Lincoln Laboratory.

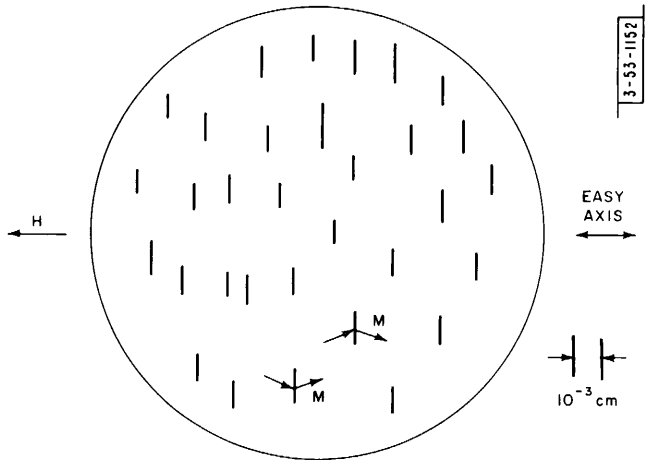
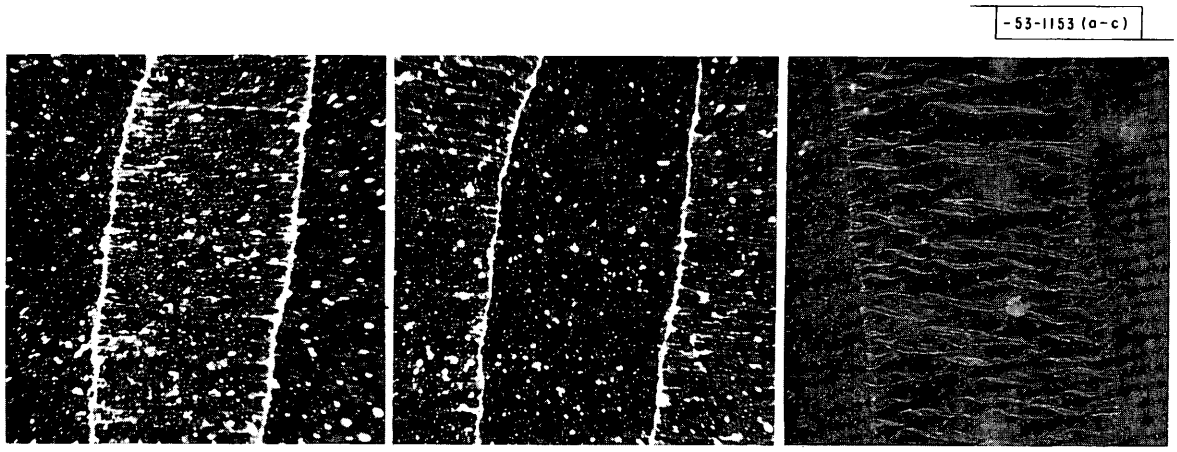


Fig. 53-5. Sketch of the Bitter pattern of an inverted film in the locked state ($H_k < H < H_w$). Rotation of M in opposite directions on either side of the disconnected wall segments is indicated.



(a) Evaporated film. (b) Same as (a) with H reversed. (c) Electrodeposited film.

Fig. 53-6. Locked and switched regions of inverted films (X250).

in opposite directions on either side of such a line segment, as indicated in Fig. 53-5. The initial stage of this rotation is found to be reversible.

Interaction between the oppositely directed regions described above inhibits further rotation, and the film is in a locked state until walls enter and complete the reversal. Figure 53-6(a) shows an evaporated film in which a wall has swept through, partially eliminating the locked region; Fig. 53-6(b) shows that reversing H simply interchanges the locked and free regions. A similar pattern for an electrodeposited film is shown in Fig. 53-6(c).

If fields are applied at angles between 180° and ~100° to M, which is originally saturated in the easy direction, the same pattern as shown in Fig. 53-5 is obtained initially. As H is increased, the wall segments rotate toward the applied field, and for angles between about 120° and 100°, the rotation continues past the applied field, becoming parallel to the easy axis.

For fields at angles 0° to 90°, the segments of Fig. 53-5 do not appear as H is increased from zero; however, for angles greater than about 45°, such a pattern somewhat rotated toward H does appear as H is subsequently reduced to zero.

Finally, the mottled appearance of the switched regions of the Bitter pattern (Fig. 53-6) should be noted and is thought to be significant.

4. Magnitude of M

The magnitude of M has been measured for a typical inverted film by two different methods: (a) resonance at X-band* and (b) statically with the vibrating-coil magnetometer. Both measurements showed M to be approximately 30 per cent lower than the normal value (~800 oersteds).

The resonance measurement makes use of the resonance conditions when the DC field is parallel and perpendicular to the plane of the film, i.e.,

$$\omega_{//} = \gamma \sqrt{(4\pi M + H_{//})\,(H_{//} + H_k)} \tag{7}$$

$$\omega_{\perp} = \gamma(H_{\perp} - 4\pi M) \quad , \tag{8}$$

where γ is the gyromagnetic ratio = 2.8 Mcps/oe for the electron spin. From this pair of equations γ and M can be determined and are found to be γ = 2.8 Mcps/oe, M = 520 emu. The frequency of measurement was 8760 Mcps and resonance occurred in fields of 1270 and 9635 oe for the parallel and perpendicular cases, respectively.

The magnetometer measurement measures the total flux in a cross section of the film so that the thickness must also be measured to determine M. A value of 550 emu was obtained, in reasonable agreement with the resonance measurement. No variation with applied field from 10 to 5000 oe was found.

5. Switching

One of the limitations in using films as memory elements is the problem of disturb sensitivity or loss of information due to unwanted wall switching. In fact, the single most important parameter for successful memory operation is the ratio H_w/H_k, which must be between about one-half and one. It might appear that inverted films would be very insensitive to wall disturb, and hence ideal as memory elements. Unfortunately it is found that the switching of these films is very slow, due no doubt to the fact that the factors that cause locking inhibit a coherent rotational switch.

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* Thanks are expressed to P. Tannenwald and M. Seavey, of Group 82, for this measurement.

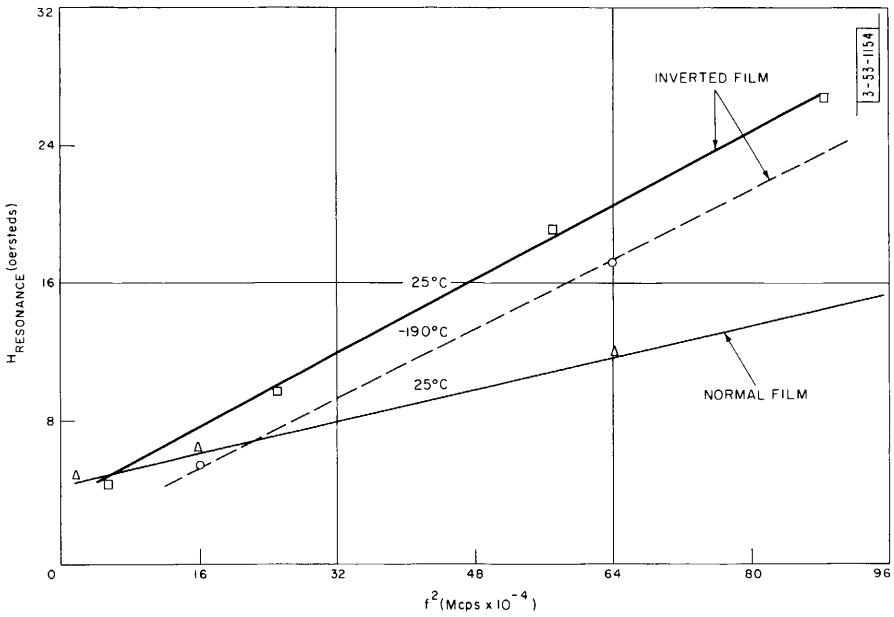

Fig. 53-7. Low-frequency resonance data for normal and inverted films.

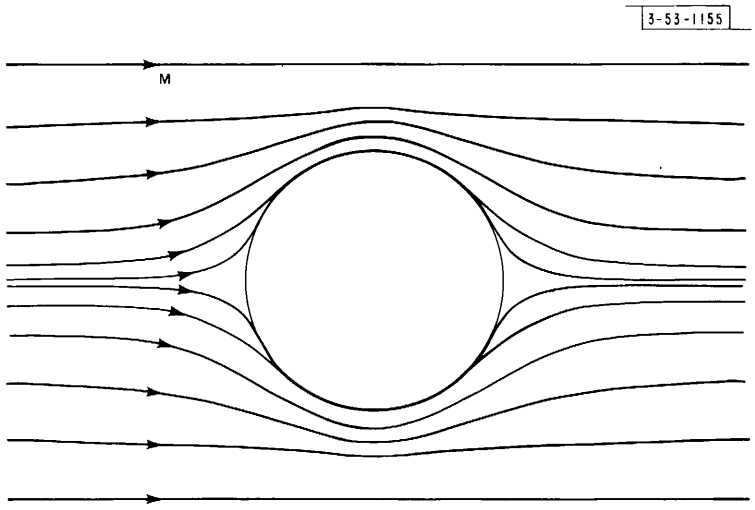

Fig. 53-8. Exclusion of flux from a void.

6. Effects of Strain

The magnetoelastic constant of inverted films appears to be nearly the same as for normal films made with the same melt composition. This indicates that there is no significant difference in composition between normal and inverted films. Strain applied to inverted films will cause a diminution, or extinction, of the locked-state striations as H_k is raised. If stress is applied in such a way as to decrease H_k and rotate the easy axis by 90°, then the striation direction rotates also and lies along the original easy axis. Thus, in a sense the striation effect is isotropic.

Stripping an inverted film from the substrate* has no major effect. The film generally stays inverted and striations continue to appear upon magnetization reversal. Thus the strain due to being tied down to the substrate plays no role. The Bitter-pattern mottling (cf. Fig. 53-6) of inverted films does not disappear upon stripping. This, plus the fact that inverted films can be made with either positive or negative magnetostriction, distinguishes this case from the mottling associated with a magnetoelastic easy axis perpendicular to the plane of the film.[14]

7. Low-Frequency Resonance

Parallel resonance [Eq. (7)] at frequencies between 100 and 1000 Mcps also yields anomalous results. For this case $H < 4\pi M$ and Eq. (7) reduces to $\omega_{//} = \gamma \sqrt{4\pi M(H_{//} + H_k)}$. Figure 53-7 shows H as a function of f^2, the slope of which should give $(\gamma^2 4\pi M)^{-1}$. For normal films the correct slope is obtained; for the inverted case this slope does not correspond to the values of γ and M found by X-band resonance and the magnetometer measurement. Agreement can be obtained by inserting an additional field into the resonance condition, i.e., $\omega_{//} = \gamma \sqrt{4\pi M(H_{//} + H_k - H_u)}$, where H_u is an unknown field that subtracts from the applied field and is also found to be frequency dependent. A possible interpretation of this effect will be given later.

8. Interpretation

All of the anomalous magnetic effects described above can be qualitatively explained by assuming that inverted films have a low density due to voids in the material. The way in which preparation could lead to a porous film has already been discussed. Three principal magnetic effects require explanation: (a) the locked state, (b) the increase of the wall coercive force and (c) the decrease in M.

Figure 53-8 shows the exclusion of flux that will occur around a void. A reversing field H will cause opposite rotation of M on the two sides of the defect, in qualitative agreement of the interpretation of the locked-wall segments of Fig. 53-5. The reversibility of this pattern for small H also follows. For H at various backward angles, the effect will persist if steep enough angles of M with the boundaries of the void exist. For H in the forward direction, the existence of a critical angle at about 45° means that some regions of the film have been rotated past the hard uniaxial directions and others not, so that when H is decreased to zero a residual pattern is set up.

The increase of the wall coercive force is illustrated in Fig. 53-9. It is known that walls in Permalloy films are of the "cross-tie" type. Such a wall separating a locked region from a switched region is shown in Fig. 53-9. On the locked side of the wall the repetitive flux pattern between cross-ties is broken up as shown, serving to increase the wall energy and also to inhibit its motion, thus raising the wall coercive force.

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*Apply Scotch tape and remove under water.

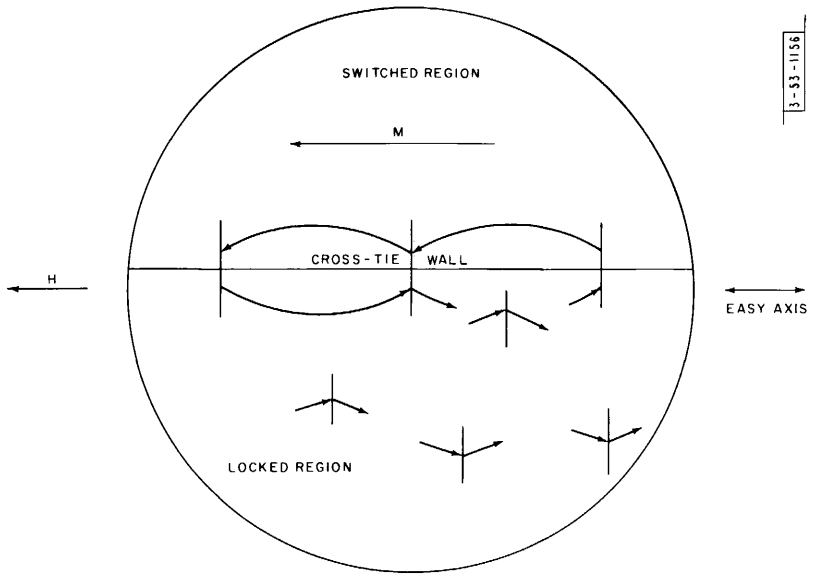

Fig. 53-9. Interaction between a cross-tie wall and the locked region of an inverted film to raise the wall coercive force.

The decrease in M which is observed also follows from the hypothesis of low density, although the two different methods of measurement, magnetometer and resonance, must be discussed separately. In the magnetometer determination the total flux is divided by the volume of the film as determined by measuring the diameter and thickness. Clearly, if the film density is low, the volume will be greater than normal and the value of M will be low.

In the case of resonance the problem is somewhat more subtle. Now the magnetization per unit volume is determined directly, without a separate measure of the volume. However, the scale at which this measurement occurs must be considered. The magnetization per unit cell is not measured, nor is the measurement on a gross macroscopic scale. It is in the intermediate range of dimensions between microscopic and macroscopic that the resonance value of M is valid. Thus it should be possible to give a quantitative estimate of the size of the voids which have been hypothesized. This has not yet been done, although a guess in the range of thousands of angstroms seems reasonable.

The remaining properties of inverted films will be discussed briefly. The slow switching is directly attributable to the locked state. The occurrence of inversion for either positive or negative magnetostriction follows immediately from the low density model as does the persistence of inversion after stripping. The rotation of the locked state on rotation of the easy axis by applied strain is also easily understood. Mottling due to voids is a reasonable idea and would be independent of stripping or the sign of the magnetoelastic constant, as observed. The anomalous low-frequency resonance results can also be explained qualitatively. The unknown field H_u is attributed to the demagnetizing fields and divergence of M at the voids in question.

9. Conclusion

The low-density model of inverted films is successful in explaining a wide variety of magnetic effects. It will be further checked by a direct measure of the density. Electron diffraction and microscopy will also be used and experiments to gain more insight into the role of the substrate and the actual growth mechanism are planned.

D. O. Smith
E. E. Huber, Jr.

C. Variation of Substrate Temperature

A study of the effect of substrate temperature T_s in the range 200° to 600°C on film composition, anisotropy, and wall coercive force has been started. It is suggested that better film uniformity might result from employing high substrate temperatures, since by this means a more reproducible substrate surface should be attainable.

For T_s up to 400°C the film composition as measured by dH_k/de (Ref. 15) does not change (Figs. 53-10 and 53-11 for melt compositions of 80 and 83 wt per cent Ni); above 400°C the film becomes more nickel-rich than usual, indicating that the ratio of the sticking coefficients for iron and nickel at the substrate is changing. At 600°C the 80-20 melt yields anomalous results. By extrapolation dH_k/de is negative; the films are mottled and the thickness exceeds the critical thickness discussed by Huber and Smith.[14]

Further experiments which avoid mottling and critical thickness effects are planned in which uniformity will be studied more extensively.

G. P. Weiss
D. O. Smith

D. Parametric Excitation in Permalloy Films

A suitably biased Permalloy film may have some promise as a parametron or as the variable parameter of a parametron circuit.

If both AC and DC magnetic fields $h_\perp$ and $h_{s\perp}$ are applied in a direction perpendicular to the direction of easy magnetization, the differential equation of motion for the angle φ between the magnetization and the easy axis follows rather easily from Smith's analysis[40]

$$\ddot{\varphi} + 4\pi\lambda\dot{\varphi} + 8\pi\gamma^2 K_1 \left[\frac{\sin 2\varphi}{2} - (h_{s\perp} + h_\perp)\cos\varphi\right] = 0 \quad , \tag{9}$$

where λ is the Landau-Lifshitz damping parameter, K_1 is the first-order anisotropy constant and $h_\perp$, $h_{s\perp}$ are normalized with respect to the anisotropy field $2K_1/M$. When $h_\perp = 0$, $\ddot{\varphi}_o$ and $\dot{\varphi}_o = 0$, Eq. (9) shows that $\varphi_o = \sin^{-1} h_{s\perp}$, and this relation is plotted in Fig. 53-12. When $h_{s\perp} \geq 1$, the magnetization is in the direction of the DC and AC magnetic fields. When a superimposed AC field $h_\perp$ is applied, the magnetization will oscillate about the direction φ_o determined by the value of $h_{s\perp}$. Thus we may let $\varphi = \varphi_o + \Delta\varphi$, where $\Delta\varphi$ would be small for small values of $h_\perp$. At low frequencies, we may expect $\varphi(t)$ to follow the φ_o vs $h_{s\perp}$ characteristic as $h_\perp$ is varied. This situation is depicted in Fig. 53-12.

The incremental permeability for $h_\perp$ when appropriately defined, is proportional to $(\Delta\varphi)\dot{\varphi}$. Thus, the rate of change of permeability is proportional to $[\Delta\varphi\, \partial^2\varphi/\partial h_{s\perp}^2 + (\partial\varphi/\partial h_\perp)^2]$. It follows that, for parametron operation, we should like to bias the film at a point where $\Delta\varphi$, $d\varphi/dh_{s\perp}$ and $d^2\varphi/dh_{s\perp}^2$ have high values so that the change in permeability with magnetic field is large. From the relation $\varphi_o = \sin^{-1} h_{s\perp}$, it follows immediately that $d\varphi/dh_{s\perp} = (1 - h_{s\perp}^2)^{-1/2}$ and $d^2\varphi/dh_{s\perp}^2 = h_{s\perp}(1 - h_{s\perp}^2)^{-3/2}$. These relations are plotted in Fig. 53-13. It follows immediately from Figs. 53-12 and 53-13 that $h_{s\perp}$ should be close to one for efficient operation. Therefore, let us consider the case where $\varphi_o = 90°$. We can then easily show that to the second order in $\Delta\varphi$, the differential equation (9) becomes

$$(\dot{\Delta\varphi}) + 4\pi\lambda(\Delta\dot{\varphi}) + 8\pi\gamma^2 K_1 (h_{s\perp} - 1)\left[1 + \frac{(\Delta\varphi)^2}{2(h_{s\perp} - 1)} + \frac{h_\perp}{(h_{s\perp} - 1)}\right]\Delta\varphi = 0 \quad . \tag{10}$$

If we let $h_\perp = H \sin 2\omega t$, we find that Eq. (10) is identical in form to that investigated by Goto[41] and others[42] in connection with parametrons using ferrites and semiconductors, respectively.

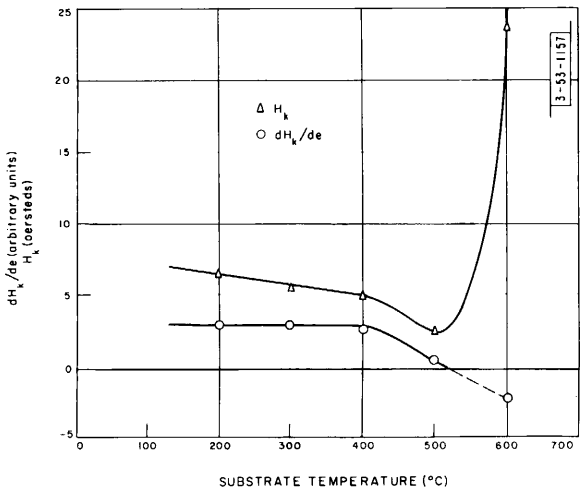

Fig. 53-10. Rotational coercive force H_k and dH_k/de vs substrate temperature (80-20 melt composition, ~1000 Å film).

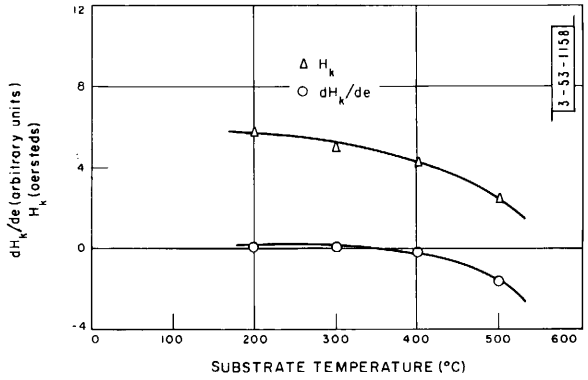

Fig. 53-11. Rotational coercive force H_k and dH_k/de vs substrate temperature (83-17 melt composition, 1000 Å film).

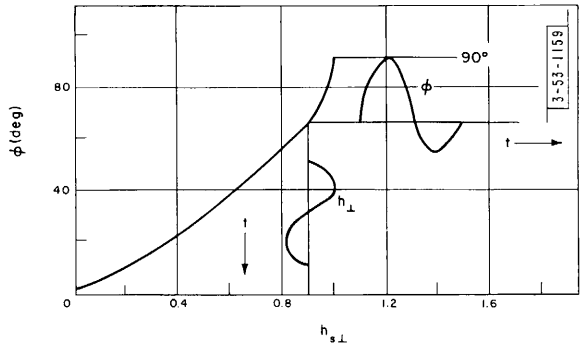

Fig. 53-12. Direction of magnetization vs normalized DC field.

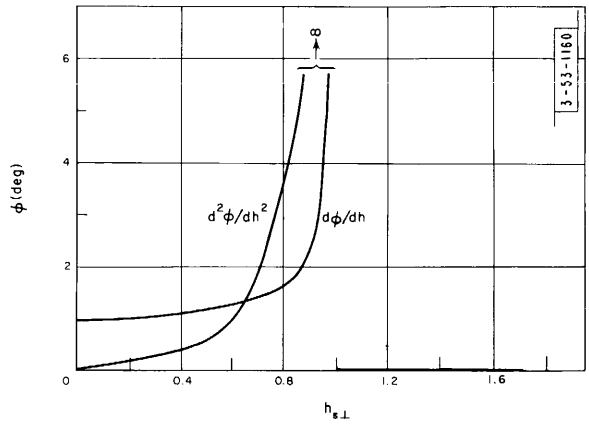

Fig. 53-13. Permeability and rate of change of permeability vs normalized DC field.

There is one important difference. In the case of the ferrite and semiconductor parametrons, the fixed capacitance and inductance, respectively, must be provided for by additional circuit elements. On the other hand, in the case of the thin film, the R-, L- and C-elements of the equivalent circuit are completely provided for by the nature of the motion of magnetization in the film.[43]

For efficient parametric pumping, we required that the pumping frequency ω should be equal, or nearly equal, to twice the resonance frequency of the system. It is interesting to note that this resonance frequency ω_o is $\gamma\sqrt{8\pi K_1(h_{s\perp}-1)}$. This implies that, for a finite pumping frequency, $h_{s\perp}$ must be larger than one, i.e., the film must be biased beyond saturation. On the other hand, the condition for oscillation can be shown to be[44]

$$H \geqslant \frac{\lambda\omega_o}{\gamma^2 K_1}(h_{s\perp}-1) \quad . \tag{11}$$

Thus, the threshold pumping amplitude increases with the signal frequency ω_o. For representative values of λ and K_1, $H \geqslant 10^{-9}\omega_o(h_{s\perp}-1)$. Therefore, if f_o were in excess of several hundred megacycles per second, the required H-field would be impractically large. We conclude, therefore, that the film by itself can be used as a low-frequency "intrinsic parametron" but at microwave frequencies, the film must be placed in a cavity, say, to obtain an over-all resonance frequency in the microwave range. This raises a packaging problem as the volume of the film to that of the cavity must not be too small, for otherwise the variation of the permeability of the film will not be sufficient to generate the required oscillations.

R. F. Soohoo

IV. SEMICONDUCTING COMPONENTS

A. Introduction

Although work on life performance testing of TX-2 transistors continues, emphasis is shifting to an evaluation of several new semiconducting devices that may provide computer components with greater switching speeds. One approach is the search for optimal transistor geometry. Another element under investigation is the "cryosar," a negative-resistance device that operates at liquid H_e temperatures. Finally, serious consideration is being given to the variable-capacitance parametron.

B. Cryosar Diode Circuits

The cryosar diode changes from a high resistance state to a low resistance state by an avalanche mechanism. Initial studies have shown the transition in either direction to be very rapid. Both normal and negative resistance diodes can be constructed for this mode of operation. Present operation is limited to liquid helium temperatures.

A computer circuit using the cryosar diode was described in the Quarterly Progress Report on Solid State Research for 15 January 1959. The apparatus was improved, and tests were run on a diode. It was not so fast as had been anticipated; at 50 Mcps the diode exhibited a firing and holding voltage as expected, but at 90 Mcps the effect was small. A diode having a smaller width and electrode diameter is presently being made by Group 81. It should be faster, but have a lower output voltage.

R. C. Johnston

C. High-Speed Transistor Performance

The present TX-2 flip-flop circuits, which use transistors of the L-5122 SBT and L-5134 MAT varieties or essentially 50 Mcps alpha-cutoff transistors, perform satisfactorily at 5-Mcps clock rates. The 2N501 MADT, a 150-Mcps transistor, has been designed into a 20-Mcps flip-flop. New transistors are being evaluated in an attempt to double this performance.

TABLE 53-III
COMPARISON OF FOUR TRANSISTORS IN FLIP-FLOP CIRCUITS

		L-5122 SBT	L-5134 MAT	2N501 MADT	2N695 Mesa
Width in mμsec of 3-volt pulse necessary to set or clear the TX-2 SBT flip-flop		16	25	15	10
Width of 3-volt pulse necessary to complement the MADT 20-Mcps flip-flop (60-cps prf)		–	35	9	19
Double pulse at complement input: Width of pulses, and delay of second pulse. MADT flip-flop	Width (mμsec)	50	25	25	
	Delay (mμsec)	200	100	100	
	Amplitude (volts)	2.6	2.46	2.44	

The 2N695 mesa has about the same frequency response as the 2N501 MADT but has about half the hole storage. As a preliminary comparison, the two transistor types were tried in two existing flip-flop circuits. The slower SBT and MAT transistors were also tried for comparison. The results are given in Table 53-III.

The results so far are inconclusive. During the next quarter a flip-flop design will be optimized for the mesa transistor, and the transistor's behavior as an amplifier of a 10-mμsec pulse will also be evaluated.

R. C. Johnston

D. Switching Characteristics of the Degenerate Reactance Amplifier

The variable-capacitance diode type of reactance amplifier shows promise as a computer component since the high cutoff frequency of the diode, in the order of 100 kMcps, should permit bandwidths of the order of 1 to 10 kMcps to be achieved. Accordingly, its switching characteristics are being studied.

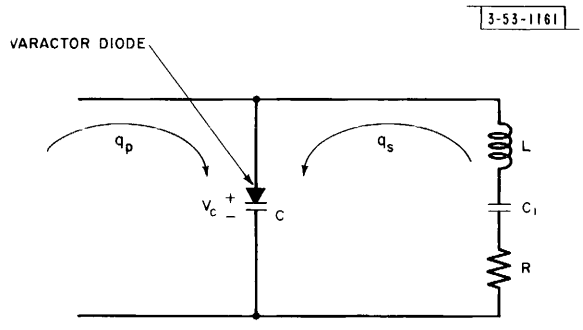

Fig. 53-14. Simplified equivalent circuit of a degenerate-reactance amplifier.

The degenerate reactance amplifier has the property of being phase bistable when operated in one of its unstable, or regenerative modes. The circuit conditions necessary to excite the lowest unstable mode (pump frequency equals twice the signal frequency) are of considerable interest when this device is to be used as a bistable computer element. The principal circuit parameters, which determine whether this unstable mode is excited or not, are the pump drive and the over-all Q of the

circuit. Once this condition for instability has been set up in terms of the over-all circuit Q, we can then specify the minimum Q of the varactor diode necessary for phase-bistable operation since the maximum Q of the circuit can be no greater than the Q of the diode.

The development of the instability condition proceeds directly from an analysis of the series equivalent circuit of the degenerate reactance amplifier shown in Fig. 53-14. Writing the loop equation for the voltage in the signal circuit in terms of the charge, we have

$$L\frac{d^2q_s}{dt^2} + R\frac{dq_s}{dt} + \frac{q_s}{C_1} + V_c(q_s, q_p) = 0 \quad . \tag{12}$$

An explicit relation for V_c in terms of q_s and q_p can be found by solving Poisson's equation for the voltage across the space-charge region of a junction diode in terms of the excess charge, $q_s + q_p$ under reverse-biased conditions.

Assuming that the varactor diode is pumped from a sinusoidal source of radial frequency ω_p such that

$$q_p = Q_p \cos \omega_p t = Q_p \cos 2\omega_s t \quad , \tag{13}$$

where ω_s is the radial signal frequency, we find that solutions of (12) for t small are of the form

$$q_s = \exp\left[\left(\pm \mu^{(r)} - \frac{1}{2Q_{ckt}}\right) \omega_s t\right] \sum_{n=-\infty}^{+\infty} B_n \exp[i(2n + 1)\, \omega_s t] \quad , \tag{14}$$

where

$$\mu^{(r)} \approx \frac{r - 1}{4\omega_s Q_{ckt} RC_o^{(r)}} \left(\frac{Q_p}{Q_o}\right) \quad , \quad Q_p \leqslant Q_o \tag{15}$$

and

$$\frac{1}{Q_{ckt}} = \omega_s RC_o^{(r)} \left[\frac{C_1}{C_o^{(r)} + C_1}\right] \quad . \tag{16}$$

Thus instability can occur in the signal circuit for the condition

$$\mu^{(r)} > \frac{1}{2Q} \quad . \tag{17}$$

Making use of (15) and (16), we find that the instability condition of (17) may be rewritten in the form

$$Q_{ckt} \frac{C_1}{C_o^{(r)} + C_1} \frac{Q_p}{Q_o} > \begin{cases} 2 \text{ for an alloy p-n junction diode} \\ 4 \text{ for a diffused p-n junction diode} \end{cases} \tag{18}$$

or, alternately, in terms of the diode Q_d, in the form

$$Q_{diode}(1 - \Gamma) \frac{Q_p}{Q_o} > \begin{cases} 2 \text{ for an alloy diode} \\ 4 \text{ for a diffused diode} \end{cases} \tag{19}$$

where

$$\frac{1}{Q_d} \triangleq \omega_s R_d C_o^{(r)} \quad ,$$

$$\Gamma \triangleq \text{"circuit efficiency"} = 1 - \frac{[\text{power out}]}{[\text{total power in at the signal frequency}]}$$

$$= 1 - \frac{R_{Load}}{R} \quad ,$$

assuming $R = R_d + R_{Load}$.

In discussing the circuit conditions necessary to excite the lowest unstable mode of the degenerate-reactance amplifier as given equivalently by either (18) or (19), we first note from (14) that the switching time of this device τ_s is given by

$$\frac{1}{\tau_s} \sim \left(\mu - \frac{1}{2Q_{ckt}}\right) \omega_s = \left[\frac{C_1}{C_o^{(r)} + C_1} \frac{Q_p}{Q_o} \frac{Q_{ckt}}{\{2,4\}} - 1\right] \frac{\omega_s}{2Q_{ckt}} \quad . \tag{20}$$

Now from (18), (19) and (20) we see that it is desirable to maximize

$$Q_{ckt} \frac{C_1}{C_o^{(r)} + C_1} \frac{Q_p}{Q_o} = Q_{diode} (1 - \Gamma) \frac{Q_p}{Q_o} \quad . \tag{21}$$

Consequently, the following circuit conditions should be observed in designing the degenerate reactance amplifier to operate in its lowest unstable mode:

(1) No capacity should appear in series or in shunt with the varactor diode in the signal circuit.

(2) Since Q_p/Q_o is proportional to the pump drive, it should be as large as possible consistent with the fact that, if no forward conduction is to be allowed, $q_p + q_s \leq Q_o$.

(3) The Q_{diode} should be as large as possible.

(4) The circuit efficiency, and therefore the power delivered to the load, should be as small as possible.

Since C_1 is not a critical component of the circuit, it is set arbitrarily at $C_1 = \infty$. Then the expression for the switching time can be rewritten from (20) and (21) in the form

$$\frac{1}{2\pi f_{co} \tau_s} = \frac{1}{2} \frac{f_s}{f_{co}} \left[\frac{Q_p/Q_o}{\{2,4\}} - \frac{f_s/f_{co}}{1 - \Gamma}\right] \quad , \tag{22}$$

where ω_{co}, the diode cutoff frequency, is the frequency at which Q_d is unity. The minimum switching time $\tau_{s\,min}$ for a given set of circuit conditions can be obtained from (22) by maximizing $1/\omega_{co}\tau_s$ with respect to ω_s/ω_{co}. Carrying out this procedure, we find that the following equation must be satisfied by the circuit parameters in order to obtain the minimum possible switching time, $\tau_{s\,min}$:

$$\frac{f_s}{f_{co}} = \frac{1}{2}(1 - \Gamma) \frac{Q_p/Q_o}{\{2,4\}} \quad , \tag{23}$$

where $\tau_{s\,min}$ is given by the relation

$$\frac{1}{2\pi f_{co} \tau_{s\,min}} = \frac{1}{8}(1 - \Gamma) \left[\frac{Q_p/Q_o}{\{2,4\}}\right]^2 \quad . \tag{24}$$

A plot of $1/\omega_{co}\tau_{s\ min}$ vs ω_s/ω_{co} for the degenerate reactance amplifier using a diffused-type diode with per cent circuit efficiency ($\Gamma \times 100$ per cent) and per cent of maximum pump drive ($Q_p/Q_o \times 100$ per cent) as parameters, as obtained from (23) and (24), is shown in Fig. 53-15. We can see from this plot that the minimum possible switching time occurs under the conditions of 100 per cent of maximum pump drive, zero circuit efficiency (i.e., the circuit is 100 per cent regenerative), and a signal frequency $f_s = f_{co}/8$. It is given in terms of the diode cutoff frequency by the expression

$$\tau_{s\ min\ possible} = \frac{19.7}{f_{co}} \quad . \tag{25}$$

Thus, for a diode with a cutoff frequency of 100 kMcps, we find that

$$\tau_{s\ min\ possible} \approx 0.2\ \text{m}\mu\text{sec}$$

if we operate at a signal frequency of 12.5 kMcps. In a more realistic situation for this same diode, we might have a circuit design where

Circuit Efficiency = 10 per cent

Maximum Pump Drive = 80 per cent.

Then we would find that $\tau_{s\ min} \approx 0.35$ mμsec if we operated at a frequency $f_s = 9$ kMcps.

C. T. Kirk

E. Transistor Testing

To enable the routine measurement of several parameters on relatively large numbers of transistors, an automatic feed for a 10-transistor cartridge has been designed (with the cooperation of Gordon Essler of the MITRE Corporation) and installed in the transistor test area. A typical installation is shown in Fig. 53-16. The standard measurements made on incoming switching transistors include seven measurements of reverse-biased characteristics: I_{co}, I_{eo}, BV_{cbo}, BV_{ebo}, BV_{ceo}, V_{pt}, V_a; four measurements of forward-biased characteristics: α, high-current β, $I_{c\ sat}$, V_{be}; and four dynamic tests: f_T, τ_s, K_s' and τ_B. Simplified schematics of the test circuits appear in Figs. 53-17 through 53-27. This material has been submitted for publication in an article co-authored by R. L. Burke.

R. C. Johnston

F. GSN-101 Symmetrical Transistor Life Tests

The GSN-101 symmetrical p-n-p alloy transistor was developed under contract by the Philco Corporation for use in transistor-driven magnetic core memories. To develop some feeling for the reliability of the device, small-scale operating and high-temperature life testing was undertaken at Lincoln Laboratory; this was completed during the past quarter and the units are now performing in operating systems. Twenty transistors were put on an operational life test that simulated a 6-μsec read-write memory cycle.* Average transistor dissipation was 62 mw in a 32°C free air environment and the approximate junction temperature was 60°C. This test was in operation for more than 3000 hours when equipment difficulties intervened. In addition, 20 transistors were placed in storage at 100°C. All transistors were periodically evaluated (Solid State Quarterly Progress Report for 1 August 1958).

*For detailed description of the test setup, see the Quarterly Progress Report on Solid State Research for 1 May 1958, p. 93.

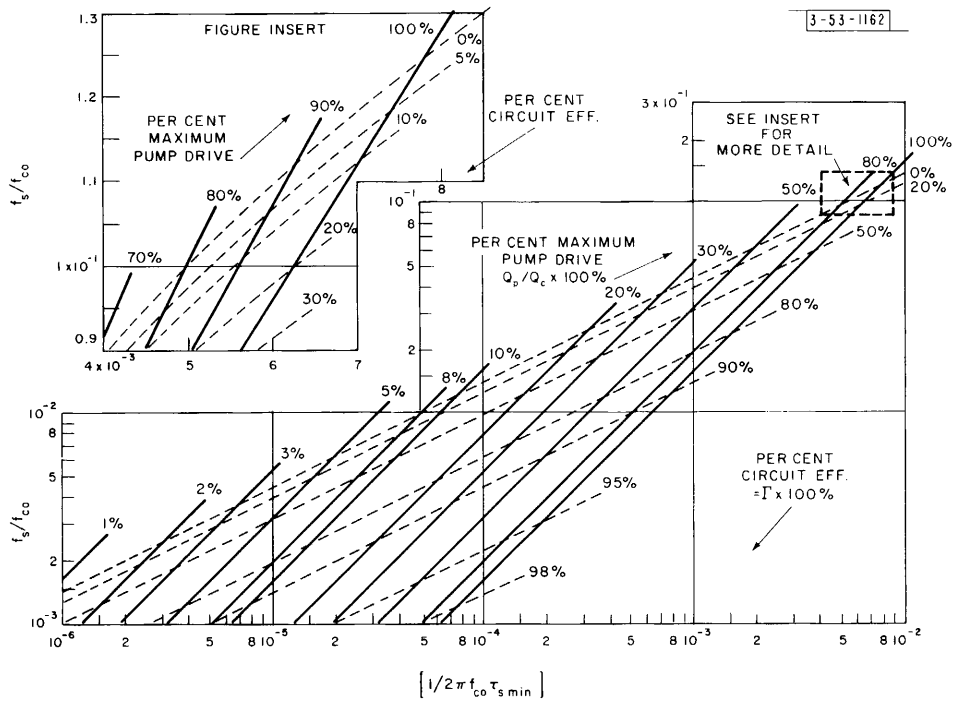

Fig. 53-15. $[1/2\pi f_{co}\tau_{s\,min}]$ vs f_s/f_{co}.

Fig. 53-16. Typical test station.

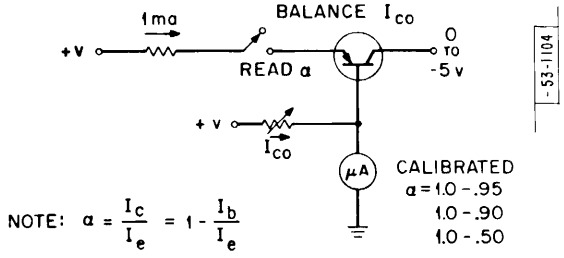

Fig. 53-17. 1-ma α test.

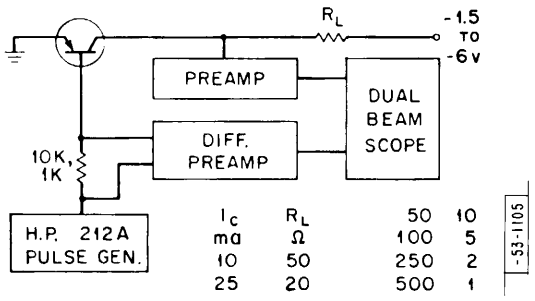

Fig. 53-18. High-current β test.

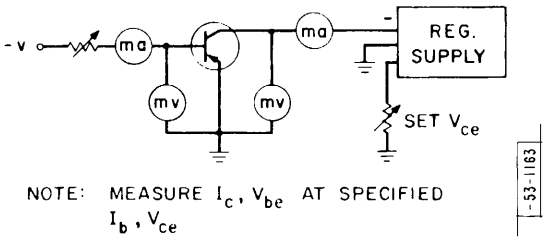

Fig. 53-19. $I_{c\ sat}$ test.

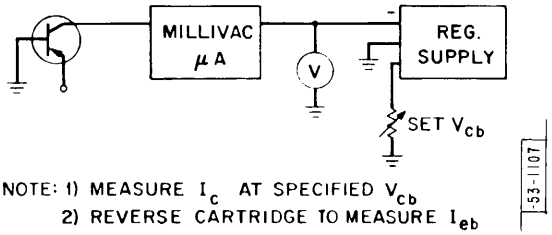

Fig. 53-20. I_{cb}, I_{eb} test.

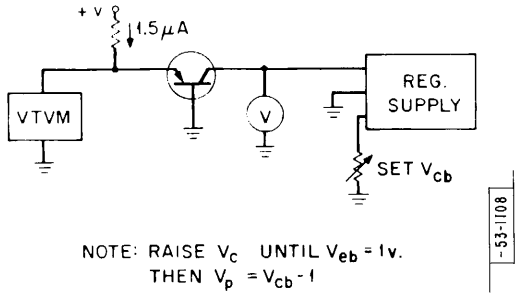

Fig. 53-21. Punch-through voltage test.

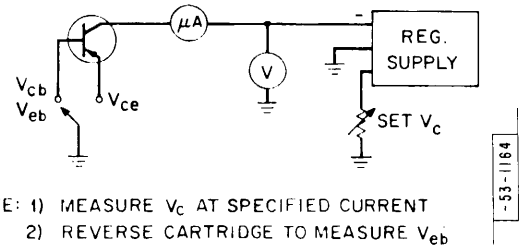

Fig. 53-22. V_{cb}, V_{eb}, V_{ce} test.

A summary of the results of these tests is given in Tables 53-IV through 53-VII. The values quoted are obtained from smooth curves drawn through the points plotted for the 20 transistors in each case. One transistor failed in each of the two tests. In the operational test this was due to accidental damage during measurement. In the storage test the failure occurred at 300 hours and was indicated by a sharp drop in punch-through voltage and 1-ma β. At 312 hours the unit had a collector-to-emitter short circuit. In all, during 160,000 transistor-hours, there was only one natural failure.

The data for the 100°C "accelerated" life test are presented at 3000 and 5000 hours. Results at the 3000-hour mark are compared with the operating test. The storage test is obviously the more severe of the two. Results in the operating test are felt to be acceptable.

P. Barck

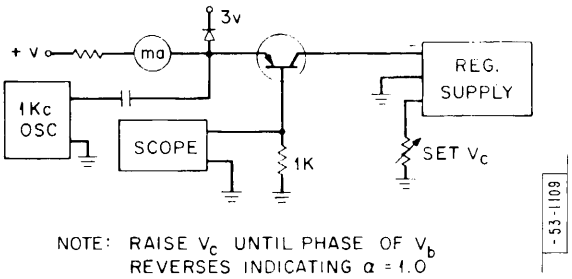

Fig. 53-23. Avalanche voltage test.

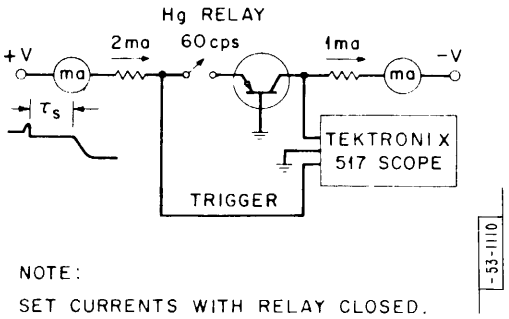

Fig. 53-24. τ_s test.

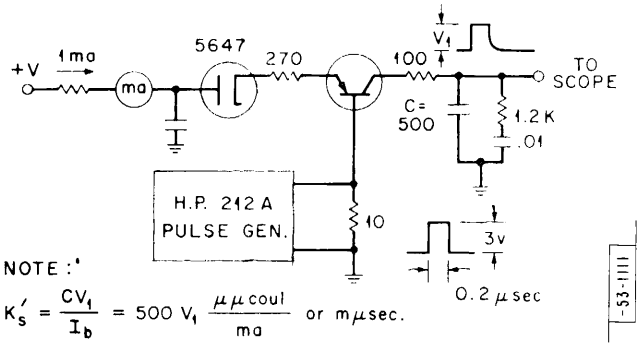

Fig. 53-25. K_s' test.

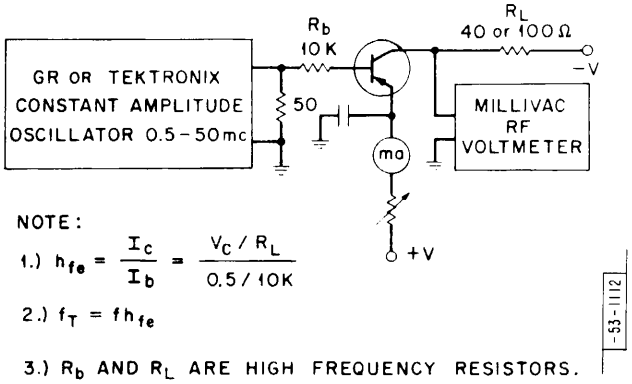

Fig. 53-26. f_T test.

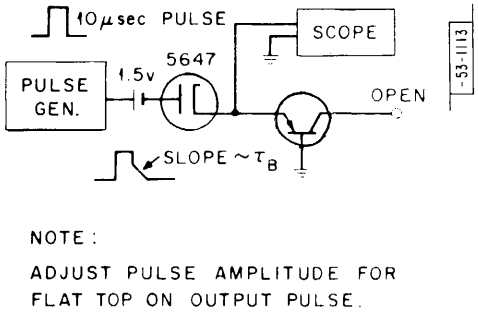

Fig. 53-27. τ_B test.

TABLE 53-IV

PHILCO SYMMETRICAL CORESWITCH TRANSISTOR (GSN-101) OPERATIONAL LIFE TEST (0 TO 3000 HOURS)

Transistor Parameter	Parameters Before Test (upper row) After Test (lower row)					Net Parameter Change					Per Cent Parameter Change				
	Low	10%	50%	90%	High	Low	10%	50%	90%	High	Low	10%	50%	90%	High
DC β_F at 1 ma, 3 volts	14 15.1	21.5 17.9	34 31.2	59 51.7	65.6 70.4	−20.9	−13.5	−3.5	+3	+4.8	−37	−33	−7.5	+12	+16
DC β_R at 1 ma, 3 volts	13.3 14.4	20.8 17.5	36.7 28.4	58 44.5	99 70.4	−40.1	−23	−5.5	+2	+3	−70.5	−47	−15	+8	+15
DC β_F at 250 ma, 1 volt	16.6 12.8	19.2 16.4	33.3 24	58.1 46.4	71.5 55.5	−17.2	−13	−8.8	−3.5	+0.7	−49	−33	−23.5	−12.5	+0.4
DC β_R at 250 ma, 1 volt	16.6 12.5	19.1 15	27.8 20	41.6 35.2	41.6 41.6	−24.2	−12	−5.5	0	0	−58	−44	−19	0	0
BV_{cbo} (volts) at 300μa	27 25	29 28	37 35	46.5 45.5	48 48	−10	−7.5	−3	+4	+8	−29	−20	−6	+13	+21
BV_{ebo} (volts) at 300μa	27 27	31 27.7	38 34	>50 47	>50 50	−9	−6.5	−2	+2	+9	−26	−18	−8	+3.5	+24
V_p (volts)	14 14	14.5 14.4	17.5 17.5	>25 24	>25 >25	Only 4 transistors changed −1		−0.5	+0.5	+1.5					
τ_s (mμsec)	175 150	320 195	480 345	740 515	900 620	−390	−260	−150	−25	0	−50	−45	−30	−9	0

TABLE 53-V

PHILCO SYMMETRICAL CORESWITCH TRANSISTOR (GSN-101) 100°C LIFE TEST (0 TO 3000 HOURS)

Transistor Parameter	Parameters Before Test (upper row) After Test (lower row)					Net Parameter Change					Per Cent Parameter Change				
	Low	10%	50%	90%	High	Low	10%	50%	90%	High	Low	10%	50%	90%	High
DC β_F at 1 ma, 3 volts	19 6.2	28.4 12.9	49 24	90 43	166 82	83.4	53	27.5	10.1	6.8	91	61	50	38	30
DC β_R at 1 ma, 3 volts	16.9 13.3	24.9 14.1	51.7 23.4	110 46	200 58	161	60	31	8	3.4	80	64	51	35	20
DC β_F at 250 ma, 1 volt	17.3 12.5	20.2 12.6	30.5 18.3	43 30	55.5 35.7	82	18.3	10.3	6.6	4.5	69	44	38	30	26
DC β_R at 250 ma, 1 volt	17.9 8.4	21.8 13.8	36.2 25	70 44	132 55.5	82	31	13.5	6	3.9	69	60	34	22	15
BV_{cbo} (volts) at 300 μa	34 16	38.5 16.5	47 24.5	>50 32	>50 38	30	28	20	16.5	10	60*	58	45	32	21
BV_{ebo} (volts) at 300 μa	41 11	42.5 16	48 21.5	>50 29	>50 47	40	33	27	15.7	+1	78*	61*	54	45	+2
V_p (volts)	11.5 11.5	14.5 14.4	17.5 17.5	>25 >25	>25 >25	Only 3 transistors changed 3.5			1.5	+5.5					
τ_s (mμsec)	280 150	310 185	530 280	750 390	800 450	500	380	265	115	100	77	54	45	35	34

* Indicates approximate values.

Note: All changes are negative unless specified.

TABLE 53-VI

PHILCO SYMMETRICAL CORESWITCH TRANSISTOR (GSN-101) 100°C LIFE TEST (0 TO 5000 HOURS)

Transistor Parameter	Parameters Before Test (upper row) After Test (lower row)					Net Parameter Change					Per Cent Parameter Change				
	Low	10%	50%	90%	High	Low	10%	50%	90%	High	Low	10%	50%	90%	High
DC β_F at 1 ma, 3 volts	19 5.3	28.4 12.9	49 23.9	90 43	166 82.3	83.4	55.5	30	10.1	6.8	99	68	51.5	37	31.5
DC β_R at 1 ma, 3 volts	16.9 12.3	24.9 13.7	51.7 23.3	110 45.9	200 57.9	160	62	31	8.5	3.1	80	72	52.5	36	18.4
DC β_F at 250 ma, 1 volt	17.3 10.8	20.2 12.5	30.5 17.8	43 25	55.5 35.8	82	20.5	11.5	7.1	4.8	69	48	40.5	32	26.8
DC β_R at 250 ma, 1 volt	17.9 7.4	21.8 13.2	36.2 24	70 42.4	132 50	82	35	14	6.5	3.9	69	60	37	21	15
BV_{cbo} (volts) at 300μa	34 13	38.5 16	47 23.3	>50 31.5*	>50 39*	35*	30	23.5	16	9	66*	60*	50.5	39	19.5
BV_{ebo} (volts) at 300μa	41 10	42.5 15.3	48 20	>50 27.3*	>50 41	40*	33.5	27.5	18.2	5	80	65*	57	50	11
V_p (volts)	11.5 11.5	14.5 14.3	17.5 17.5	>25 >25	>25 >25	Only 3 transistors changed 3.5			1.5	+5.5					
τ_s (mμsec)	280 155	310 183	530 274	750 375	800 450	495	450	275	115	95	78	60	47	36	34

* Indicates approximate values.

Note: All changes are negative unless specified.

TABLE 53-VII
COMPARISON OF LIFE TEST DATA

Per Cent Parameter Change of:
0 to 3000 hours Operational Life Test (upper row)
0 to 3000 hours 100°C-Storage Life Test (lower row)

Transistor Parameter	Low	10%	Median	90%	High
DC β_F at 1 ma, 3 volts	−36.9 −91	−33 −61	−7.5 −50	+12 −38	+16 −30
DC β_R at 1 ma, 3 volts	−70.5 −80	−47 −64	−15 −51	+8 −35	+15 −20
DC β_F at 250 ma, 1 volt	−49 −69	−33 −44	−23.5 −38	−12.5 −30	+0.4 −26
DC β_R at 250 ma, 1 volt	−58 −69	−44 −60	−19 −34	0 −22	0 −15
BV_{cbo} (volts) at 300μa	−29 −60*	−20 −58	−6 −45	+13 −32	+21 −21
BV_{ebo} (volts) at 300μa	−26 −78*	−18 −61*	−8 −54	+3.5 −45	+24 +2
τ_s (mμsec)	−50 −77	−45 −54	−30 −45	−9 −35	0 −34
V_p (volts)	no notable changes				

* Indicates approximate values.

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PATTERN RECOGNITION
GROUP 54

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PATTERN RECOGNITION
GROUP 54

I. INTRODUCTION

We are studying pattern recognition processes at several levels. MAUDE has been rebuilt to include several improvements, and other experiments and studies are aimed at improving the demodulator and the editing. We are also interested in automatic acquisition of a pattern's attributes; this is usually termed "learning," and much of the work in the group is directed at a broad spectrum of examples. This is usually being done on a computer, but some is merely paper work and some is expressed in actual equipment. It appears likely that reasonable learning (in a human sense) needs a very large amount of data processing; thus we are interested in parallel processing and parallel mechanisms, and, consequently, in the self-organization of such functions.

O. G. Selfridge

II. MAUDE

A. MAUDE Tests

We have been working on the problem of mechanizing the decoding of radio-received, hand-sent Morse Code signals. In January 1958, a first laboratory model of MAUDE (Morse Automatic Decoder) was completed. At present, a second laboratory model is nearing completion. It is the purpose of this summary to describe the main results of the work up to now.

It is the variability among senders which makes recognition of hand-sent Morse an appreciably more difficult problem than, for example, recognition of variable-speed machine-sent Morse. The first model of MAUDE took account of this fact through the "rules of 6," whereby the longest and shortest of 6 successive spaces and the shortest of 6 successive marks were, with very high probability (and independently of the sender) "tagged" correctly. These "tagged" marks and spaces were then presumed to give a good indication of the characteristics of the particular sender and were thereupon used as the basis for simple threshold decisions as the remaining symbols.

Fifty-three different senders were decoded on an IBM 704 MAUDE simulation program. It was found that 15 out of a total of 184 messages had greater than 10 per cent of the characters garbled. This implied that the original design, which was based on an assumed fixed relation between (a) those symbols tagged by the "rules of 6" and (b) the remaining symbols, left much to be desired. A modified IBM program was tried wherein the relation between symbols of (a) and (b) could be varied with the sender. Only 4 out of 184 messages had more than a 10 per cent garble rate. We felt that this modification should be built into the design of a new laboratory model.

Our data analysis also showed that about half of MAUDE's errors were due to added or missing marks or spaces, which could be caused by operator lapses or too noisy a signal. To alleviate these types of errors requires more sophisticated input and output equipment. At the input, the problem is what are the properties of a demodulator which can best detect a noisy, fading telegraph signal with possible frequency drifts? At the output, errors of this type can be corrected only by having contextual rules of a higher order than those determined by the Morse alphabet (for example, a word recognizer).

Work on the demodulator is reported in Secs. II-B and C.

An IBM 704 program, using a 190-word vocabulary, is being designed for the reconstruction of garbled text. For the initial runs, all word space information has been thrown away. Thus far, we have succeeded in reconstructing word spaces between ungarbled words. Although it seems foolish first to remove all word spaces and then try to reconstruct them, it should be pointed out that this reconstruction operation necessitates determining whether a given sequence of letters is really a word or merely a subword (such as at in cat). Clearly this is one of the basic problems of degarbling and the present program has gone a long way toward a solution.

B. Gold

B. Demodulator Studies: Probability Measurements for Filter-Limiter-Filter Receiver

Thresholds of detection for a sine wave in noise were estimated for a wideband filter-limiter-narrowband filter scheme using a random walk model and simulation on the 704. The results appeared in Group Report 54-1.*

Distributions measured by P. L. Fleck of Group 34 disagreed strongly with those of the random walk model except at low error probabilities or high bandwidth ratios. These results will be in Group Report 54-3.* The measured results showed, in particular, that small bandwidth ratios are best whereas for the random walk model, high ratios are best.

The system was then (finally) simulated "exactly" on the 704 and frequencies obtained which are substantially the same as those measured.

W. Doyle

C. Demodulator Studies: Mathematical Investigations

Some progress has been made on the low-pass (one-dimensional) filter-limiter-filter problem by the diffusion equation method, but no final solution is at hand.

W. Doyle

III. LEARNING

A. Pandemonium Studies

Pandemonium is a model of an essentially parallel pattern recognition and learning process.[1] It is being simulated on a sequential computer, but experimental equipment is being designed as well. The choice of a suitable problem is crucial. At present we are concentrating on Morse Code translation, like MAUDE, because it represents, in miniature, a world of complexity which can yet be somewhat analyzed.

O. G. Selfridge

B. Dynamic Programming and Adaptive Processes

To illustrate our general problems we can use the one-dimensional smoothing process. This requires us to minimize the cost functional

$$H_N(x) = \sum_{j=1}^{N} \{a_1(j)[x(j) - d(j)]^2 + a_2(j)[x(j) - x(j-1)]^2\} \qquad (1)$$

* Not generally available.

by optimal choice of a policy $x(1), x(2), \ldots, x(N)$, where

$$x(0) = c \tag{2}$$

is given. The terms inside the braces in Eq. (1) may be thought of as the costs of not meeting the demand d(j) at time j and of changing from position x(j − 1) to position x(j), respectively.

If we define $f_n(z)$ as the minimum achievable cost from j = n to j = N, given x(n − 1) = z, then we have

$$f_n(z) = \min_x \{a_1(n)[x - d(n)]^2 + a_2(n)[x - z]^2 + f_{n+1}(x)\} \quad . \tag{3}$$

Now we can show that

$$f_n(z) = w(n)[z - v(n)]^2 + u(n) \quad , \tag{4}$$

and then use Eq. (3) to obtain simple recurrence formulas for u(n), v(n), and w(n) in terms of $a_1(n)$, $a_2(n)$, u(n + 1), v(n + 1), w(n + 1), and d(n). A similar formula for the optimal x(n) involves z also. These recurrence formulas enable us to solve the minimization problem by working backwards from n = N to n = 1, provided we know the values of the d(n).

If the d(n) are unknown we can think of them as forming a stochastic process. We then modify Eq. (1) by putting an expected value "E" on the right side. If we replace d(n) by its expected value in all of the recurrence formulas described above, we find that they still yield the correct optimal policy $x(1), x(2), \ldots, x(N)$.

However, even the mean of the stochastic process may not be known. If this is the case we must estimate it more exactly as the process proceeds, modifying our optimal policy accordingly. It is this necessary modification that leads us to call such a process an adaptive process.

The work described above is now complete (see Ref. 2). So are generalizations that permit x(n) to be an s-dimensional vector and incorporate higher-order differences in the cost functional. A further generalization is now under consideration, permitting more general functions than quadratics to appear in the cost functional. Some progress has been made in this direction.[3]

If we examine the solution described above, we find that we must look all the way to the end of the process (n = N) in order to determine x(1) optimally. This may be burdensome if N is very large, and impossible if we allow N = ∞. Suppose, instead, that we merely look m stages ahead at any time, where m << N, and do the best we can within this limitation. Does the policy so obtained, called the optimal m-truncated policy, have any analyzable properties, and how does it compare with the optimal policy? This question is now under active consideration, and partial answers have been obtained for both parts. They are not sufficiently concise to be included here.

A general introduction to dynamic programming will be found in Ref. 4 and an introduction to its use in adaptive processes in Ref. 5.

M. Freimer

IV. COMPUTER

A. Random Numbers

Practical random sequence generators often make use of scintillation detectors and radioactive sources. Such devices are not available in a true "logical" automaton.

A search for an adequate criterion for the "randomness" of an individual sequence of bits has led to the following formulation: A bit sequence is random if no finite automaton can predict it.

More precisely, consider a sequence of bits $s = (s_i)$. For a finite automaton M for which this sequence is an admissible input, consider the output sequence (m_i), where m_{i+1} is the output of M after the first i inputs, $s_1, \ldots, s_i$ have been received. Then a measure of how well M predicts s is

$$\varphi_M(s) = \lim_{n\to\infty} \sum_{i=1}^{n} \frac{1 - 2(s_i - m_i)^2}{n} ,$$

the average excess of right guesses over wrong guesses.

We then have as definition:

A sequence s is random if for every finite automaton M, $\varphi_M(s) = 0$.

We have proved a very satisfying theorem in connection with this:

There exists a computable random sequence.

In other words, there is a Turing machine which will spew out a certain definite sequence of bits, which sequence is random in the above defined sense.

M. Minsky
R. Silver

B. Service Programs

Twenty-one programs for the IBM 704 digital computer were written and incorporated into the Fortran system as functions. These programs were intended to improve Fortran's utility to include a large class of logical problems and machine functions not otherwise usable in Fortran. They enable one:

(1) To handle alphanumeric information (characters) in a flexible manner,

(2) To provide linkage with programs written in other systems,

(3) To plot points and write lines of characters on the CRT under control of Fortran FORMAT statements,

(4) To utilize a pseudorandom number generator,

(5) To save and restore a program that needed to be interrupted,

(6) To provide certain input-output facilities not originally present in the Fortran system.

An effort is now under way to modify these programs so as to permit their use in the Fortran 709 system.

R. Silver

V. MISCELLANEOUS

A. A Voltage Squaring and Summing Circuit Using Thyrite

A very simple circuit for performing the operation $\sum_n (E_n - E'_n)^2$ is shown in Fig. 54-1. The nonlinear elements or varistors are made of "Thyrite," or silicon carbide, of such composition that, to the first approximation, the current-voltage characteristic follows a cubic law. That is, $i = ke^3$, and $g = (di/de) = 3ke^2$, for each element. For the combination of two such elements in series, $G = (3/2)\,kE^2$, where G is the total conductance looking into the circuit and E is the total voltage across the combination. The input conductances of several such

circuits, may be summed while still maintaining DC voltage isolation of the different circuits by simple parallel connection through blocking condensers, as shown. The total conductance is best measured with an AC bridge circuit operating at some convenient frequency; the output of the bridge circuit may be synchronously detected to give once again a DC output signal.

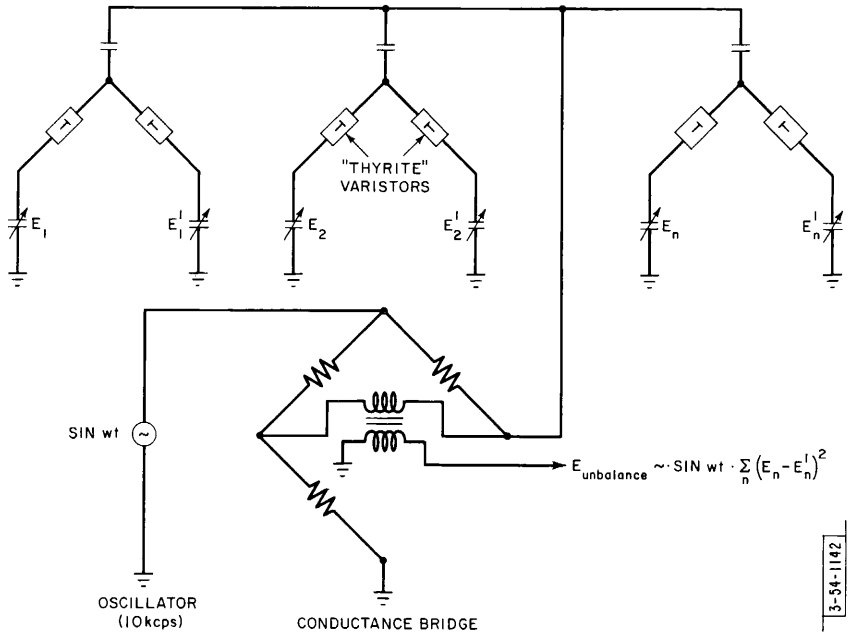

Fig. 54-1. Voltage squaring and summing circuit.

This circuit will probably not be competitive with other types of square law circuits if the summation index n is a small number, because of the complexity of the bridge and detection circuitry required to recover a DC signal. The circuit will be most useful where a large number of squares of voltages, or differences of voltages, are to be summed with moderate accuracy in a time of a fraction of a millisecond or so.

B. Howland

B. Statistics

Let M be a set of probability measures on a σ-field S of subsets of X. If there is a finite measure m_o with respect to which all measures in M are absolutely continuous, we say M is dominated. In this case the following theorems hold:

Theorem 1: There is a best sufficient subfield for M.

Theorem 2: If G is a bounded function on M, there is a measurable function f which minimizes

$$\sup_{m \in M} \int |f - G(m)|^p \, dm \quad \text{if} \quad 1 < p < \infty \quad .$$

If W(m) is the weak unit ball in the L_p-space of m for some fixed p, $1 < p < \infty$ then $P = \pi_{m \in M} W(m)$ is compact. The set B of measurable functions whose absolute value is bounded by 1 has a natural map α into P. The above theorems still hold under the assumption that $\alpha(B)$ is closed in P and hence compact. This condition is more general than domination.

Let X be the real line, S the Borel sets, m a probability measure on (X, S) and define m_λ by

$$\int f(x)\, dm_\lambda(x) = \int f(x-\lambda)\, dm(x) \quad .$$

The set $M = [m_\lambda \,|\, \text{all real } \lambda]$ is dominated if and only if m is absolutely continuous with respect to Lebesgue measure. If m has atoms $\alpha(B)$ is not closed. The case where m is singular and nonatomic is not known.

Let X be the space of sample functions on some interval I of the real line, S the σ-field generated by the sets $[f \,|\, f(t) \in A]$, $t \in I$ and A a Borel set on the real line. Every stochastic process with parameter set I determines a probability measure m on (X, S). For any function f on I define m_f by

$$\int \varphi(g)\, dm_f(g) = \int \varphi(g-f)\, dm(g) \quad ,$$

and let $M = [m_f \,|\, f \in L]$ where L is some linear space of functions on I. The set M may be dominated (for the Gaussian case see Ref. 6). When the stochastic process is stationary and L is generated by a single element, it is sometimes possible, by using an ergodic theorem, to find disjoint sets A_λ in S with $m_{\lambda f}(A_\lambda) = 1$. In this case, by judiciously extending the field S, $\alpha(B)$ can be made closed. The case where m_f and m_g are totally singular whenever $f \neq g$ is not known.

The problem of whether $\alpha(B)$ is closed or not can be formulated in another way. The set M of all signed measures on (X, S) which are absolutely continuous with respect to some countable collection from M, with total variation for a noun, is a Banach space. Sreider[7] has shown that the unit ball in its dual space is isomorphic to the closure of a(B).

Define, for measurable f, $||f|| = \sup_{m \in M} (\int |f|^p\, dm)^{1/p}$. The set H of all f with finite norm is a Banach space. It can be shown that H is reflexive if and only if M is compact in a certain topology induced on it by the sets in S considered as functions on M. This compactness implies domination but is not implied by it. In the case where X is the real line, S is the Borel field, and m is absolutely continuous with respect to Lebesgue measure, the set $M = [m_\lambda \,|\, \lambda \in I]$ gives a reflexive H if and only if the interval I is finite (with or without its end points). When H is reflexive, we can characterize the estimable functions as follows.

Theorem 3: If H is reflexive then a function F on M has an unbiased estimate in H of norm $\leqslant a$ if and only if for every $m_1, \ldots, m_k$ from M; $a_1, \ldots, a_k$; and $\epsilon > 0$ there is an h in H of norm 1 satisfying

$$\left| \sum \alpha_i \int h\, dm_i \right| \geqslant \left(\frac{1}{a-\epsilon}\right) \left| \sum \alpha_i F(m_i) \right| \quad .$$

T. Pitcher

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ANALYSIS
GROUP 55

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ANALYSIS
GROUP 55

I. INTRODUCTION

The domain of interest for Group 55 consists of: (1) mathematical problems arising specifically in the study of information processing and communications, and (2) any mathematical developments relevant to the work of the Laboratory. To make clearer what is meant by the first class of problems, we can state some typical problem-areas:

(a) Information theory (information rate and channel capacity),

(b) Algebraic coding theory (error-correcting codes, encoding and decoding procedures),

(c) Queuing theory (in particular, waiting time and waiting line distributions of information bits in a buffer storage in a digital computer),

(d) Traffic flow in networks,

(e) Statistical decision theory (for example, as applied to the design of a communications receiver to work in the presence of some specified kind of random disturbance).

Obviously this list is not intended to be either definitive or exhaustive.

The present and continuing work of Group 55 that falls into the areas listed above may be described briefly as follows.

One of the members of the group[1] (and persons outside the Laboratory[2]) has established strong connections between the entropy of a source (in the sense of information theory) and the Hausdorff-Besicovitch dimension of certain sets. This work is being extended. The interpretation of entropy and channel capacity in terms of Hausdorff dimension is a quite recent development that could potentially enhance the understanding of the concepts of information theory.

Another member of the group has studied intensively the properties of linear-recurrent sequences.[3] The resultant theory is fundamental for the design of shift registers in digital data processing equipment. Extensions and applications of this work to algebraic coding theory are being made. An analysis of the transient behavior of certain queues has been done[4] and similar work is being continued. For applications of queuing theory to digital computers, it seems pertinent to find transient (instead of just the steady-state) waiting line and waiting time distributions, and it is certainly important to determine the properties of queues imbedded in a network. The writer has worked on certain statistical problems of radar and radio receiver signal processing[5] and will continue to do so.

Another area with which the group is concerned is differential equations. In particular, work has been done in this field which is relevant to the behavior of missile and satellite trajectories.[6]

W. L. Root

II. INFORMATION THEORY STUDIES

In a previous report (Group Report 32-1) we established a connection between the entropy of a source $\{X, \mu\}$ and a metric property (Hausdorff-Besicovitch dimension) of the corresponding set on the line, under the mapping

$$x = \sum_{i=0}^{\infty} x_i M^{-i} \quad ,$$

where the x_i take values $0, \ldots, M-1$, corresponding to symbols of the source. We completed studies of sets on the line defined by analogous restrictions on what amounts to the canonical continued fraction expansion of x, i.e., the unique series of numbers, n_i such that

$$x = x_1 \quad , \quad (x_i)^{-1} = n_i + x_{i+1} \quad ,$$

where $0 \leqslant x_{i+1} < 1$. We investigated analogous metric properties connected with the value assumed by an analytic function of a complex variable defined on the unit circle, under various restrictions on tangential approach to the boundary.

Preliminary work on the analysis of storage requirements of the stations of a processing network has begun.

J.R. Kinney

III. ON GENERAL MEASURE THEORY

Let P be a set and let S be a set of functions with domain P and range in the closed unit interval such that

$$\text{If } f(a) = f(b) \text{ for all } f \in S \quad , \quad \text{then } a = b \quad . \tag{1}$$

For each $a \in P$ there exists $b \in P$ such that $f(b) = 1 - f(a)$ for all $f \in S$; there exists $c \in P$ such that $f(c) = 0$ for all $f \in S$. Both b and c are unique by (1); the first, which depends on a, is denoted a' and the second is denoted 0 . (2)

Define $a \leqslant b$ to mean that $f(a) \leqslant f(b)$ for all f. Then $a \to a'$ is an orthocomplementation in P and, defining $a \perp b$ to mean that $a \leqslant b'$, we assume

If $\{a_i\}$ is a sequence of pairwise orthogonal elements of P, there exists $a \in P$ such that $f(a) = \Sigma f(a_i)$ for all $f \in S$. Clearly a is unique and we write $a = \Sigma a_i$. (3)

Such a pair S, P may be regarded as the set of states and events, respectively, of an "abstract physical system" (Ref. 7). It is not difficult to show that, if $\{a_i\}$ is pairwise orthogonal, then $\Sigma a_i = \mathrm{V} a_i$; that certain other sups and infs exist in P – e.g., ba' if $a \leqslant b$ – and that P satisfies the weak modular law: $a \leqslant b$ implies $b = ba' \mathrm{V} a$. An extensive investigation of such general measure domains has just been completed (some results have been mentioned in previous Division 3 Quarterly Progress Reports); in the past quarter, the following results were obtained.

Let O_b denote the set of all one parameter familes A of elements of P such that for some $M \geqslant 0$ depending on A,

$$\mathrm{V} A_t = 1 \quad , \quad \Lambda A_t = 0$$
$$-M \leqslant t \leqslant M$$

and $s \uparrow t$ implies $A_t \uparrow A_s$ (the elements of O_b are analogues of essentially bounded real-valued measurable functions). Results due to Kadison[8] in the case where P is a lattice of projections on a Hilbert space and O_b is the set of self-adjoint operators in a C^*-algebra whose spectral families belong to P have been extended to the general case and yield there, inter alia, a characterization of "simultaneous measurability" for a pair of events with the following corollary: P is deterministic (i.e., a Boolean algebra) if and only if O_b is a lattice in the partial ordering

$$A \leqslant B \text{ if and only if } L_A(f) \leqslant L_B(f) \text{ for all } f \in S \text{ where } L_A(f) = \int \lambda \, d f(A_{(-\infty, \lambda)}) \quad .$$

Define a basis for P to be a subset P_o of P such that every element of P may be expressed as a join of elements of P_o. We have shown that the order relation in P is completely determined by the orthogonality relation in any basis. This leads, in particular, to a much briefer and perhaps more intuitive derivation of the model for elementary quantum mechanics (in which P is the lattice of projections of a separable infinite dimensional Hilbert space) than that previously obtained, for P_o may be taken to be the set of points (minimal nonzero elements) of P and we need show essentially only that the appropriate axioms imply that the orthogonality relation behaves correctly in the lattices under "finite dimensional" elements of P.

N. Zierler

IV. COUNTERS WITH DEAD TIME

A counter problem was considered in which events were happening according to a Poisson law. The counter was assumed to have a fixed dead time after each event is counted. This problem arose in connection with the design of a random number generator.

With no dead time, the probability that an even number of events is counted in a given time interval is very close to one-half if the average number of events occurring in that interval is large. The purpose in looking at this problem was to determine the effect of the dead time on the probability that an even number of events is counted. The probability than n or more events are counted in an interval of length T is

$$\int_o^{[T-(n-1)u]m} \frac{s^{n-1}}{(n-1)!}\, e^{-s}\, ds \quad \text{for} \quad n \leqslant \frac{T}{u} + 1 \quad .$$

For $n > \frac{T}{u} + 1$, the probability is, of course, zero. Here, m is the average number of events in a unit time interval and u is the length of the dead time.

J. D. Lordan

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PSYCHOLOGY
GROUP 58

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PSYCHOLOGY
GROUP 58

I. INTRODUCTION

The work of Group 58 is concerned with the psychological study of human capabilities and limitations, and their relevance to the design and operation of information-processing systems. One objective of this work is to achieve better coordination of men and machines in complex systems. The development of effective procedures for communication between men and machines is relevant not only to operators working with machines in real-time systems, but also to programmers and research workers using machines to solve problems and to organize and retrieve data. A study now under way concerns the development of a computer program for the automatic recognition of spoken words. Considerable success has been achieved in recognizing English monosyllables spoken by many different voices. A parallel project that has just started is concerned with separating a continuous speech wave into syllables. The segmentation of the speech wave is a necessary precursor to the word-recognition program, in order for the computer to recognize connected discourse.

A second objective of the work of the group is to gain a better understanding of the human information-processing systems involved in such complex tasks as pattern recognition, concept formation, judgment, and decision-making. Although these studies may suggest new procedures for automatic data processing, they are being pursued mainly as basic psychological research. Several studies of visual form perception are under way, in which computers are used to generate the complex, changing patterns that serve as stimuli in the experiments. In one such study, computer-generated displays have been used to investigate the kinetic depth effect, an aspect of visual space perception which would require considerable data processing to achieve automatically, but which the human does continually and effortlessly.

In conducting substantive studies, members of the group have had to deal with some methodological problems that are of general interest. These contributions are reported separately, to emphasize their status as work necessary for and antecedent to substantive investigations. One project of special interest is the adaptation of the Newell-Shaw-Simon Information-Processing Language for the Laboratory's 709 computer. This programming language will facilitate studies of complex information-processing systems.

Not all of the group's effort is devoted to experimental research. W. P. Harris has been consulting with other groups in the Laboratory that are implementing the Cross Over study, and for the past two months has been involved in the Atlantis study project. R. T. Mitchell is regularly consulted by other groups both inside and outside the Laboratory, on visual problems, particularly on the design of visual displays, and the design of lighting systems for operations rooms in man-machine systems.

II. MAN-MACHINE COMMUNICATION

A. Speech Recognition

Previous success at programming a computer to recognize spoken digits has prompted work on a more general speech recognition program. As a first step, a program has been developed to recognize ten English vowels in isolated words of the form /b/--vowel--/t/; e.g., bit, bet, bat.

Input to the computer was obtained by passing the audio speech signal through a bank of 35 band-pass filters that spanned the speech frequency spectrum. An analogue-to-digital converter sampled each filter in turn, once every 6 msec, and converted the output of each filter to a digital amplitude. The program, which was developed from an analysis of the data from 16 speakers, makes an initial attempt to classify the vowel by determining the approximate frequencies of the first two formants (energy bands in the speech spectrum). The remaining confusions are resolved by combinations of the following, as required: (1) the frequency of the third formant, (2) the rates of change of the first two formant frequencies, (3) an estimate of pitch, (4) the energy in the frequency band between the first two formants. Whenever the over-all power is above an arbitrary threshold, each 6-msec scan of the filtered data is classified as one of the ten possible vowels. At the end of the word a majority rule determines the final decision. The over-all recognition score for the 16 subjects (8 male and 8 female) used in developing the program, is 91 per cent. The score for five additional speakers was 82 per cent. Attempts to further improve this score have been postponed until other consonant environments have been studied.

Carma D. Forgie
J. W. Forgie (Group 51)

B. Syllable Segmentation

A method of segmenting speech into syllable-like units is being investigated. The plan of the investigation is to use 709 computer programs to simulate an electronic speech-segmenting device. The first such program has been written and is being checked out. It detects a number of features or configurations of the amplitude envelope of the speech wave. In a stretch of speech about 10 seconds long the program records the times at which the amplitude goes over certain limits and goes back under them. It detects the times at which the slope of the envelope changes from negative to positive, and from positive to negative. It also detects fast changes in slope. A second program is being written which will use the results of the first program as input to a simulated logical decision network. The output of the decision network will be the times at which segmentation points (syllable boundaries) occur.

A. N. Stowe

C. Tracking Through Noise

The study of human performance in tracking targets on visually noisy displays is continuing.* Previous work has been mainly concerned with the ability of operators to track targets when the data rate was 1 display/3 seconds. Currently we are concerned with what happens when film strips, containing targets moving through a field of randomly-positioned noise dots, are displayed at a very rapid rate (20 frames/second). Under some noise and target blip-scan conditions, we should expect the target to be perceived as a coherently moving object, with the random noise providing little interference. If this were true for a large range of conditions, this presentation technique, known as time-compression, would be very useful for tracking tasks such as ours or other similar tasks.

We are now performing a preliminary experiment in which the number of targets to be tracked, the noise level, and the target's blip-scan rate are varied. Operators are shown

*A. K. Wolf and B. F. Green, Jr., "Tracking Studies. III. Human Performance on One, Two, and Four Target Displays," Group Report 58-1, Lincoln Laboratory, M.I.T. (27 January 1959) (not generally available).

movie projections of computer-generated film strips on which one, two, or four targets move through a background of randomly positioned noise dots at the fixed rate of 20 frames/second. Each target starts outside the area of the noise, moves on a straight course into the noise, and turns once at a randomly determined point. A particular film strip is repeated from beginning to end a number of times. The operator's task is to locate the last position in each target's course.

Alice K. Wolf

D. Visual Psychophysics

Equipment is being constructed and assembled to provide facilities for general research in visual psychophysics. The principal unit is a modification of the Visual Discriminometer designed by Crozier and Holway.* This instrument provides two stimulus areas in the visual field which are independently variable in intensity, wavelength, duration, size, and position. A power-driven intensity control with automatic recording has been provided for one channel in order to make the equipment suitable for use with the "up-down" or "staircase" method of threshold determination. A subsidiary unit to provide controlled light adaptation conditions is being designed.

The first experiment planned is a redetermination of the relationship between the intensity of pre-adapting luminance and the time required for the eyes to dark-adapt. This study is prompted by the fact that the existing "standard" determination of this relationship is inconsistent with accepted theoretical views of the photochemistry of the retinal receptors.

R. T. Mitchell
Rhoda Resnick

III. HUMAN INFORMATION PROCESSING

A. Pattern Recognition Display Program

Work continues on two display programs designed to be used in connection with research on human pattern recognition. One program provides a two-dimensional random walk for all the coordinates in a visual pattern. The number of steps in the walk and the step size are determined by parameter cards. The other program provides for the transformation of one pattern into another in a given series of steps.

In the past quarter, both of these programs have been modified so that a greater variety of patterns may be used as inputs. The random walk program now has provision for computing a statistical index (chi-square) after each step to give an estimate of the degree to which the coordinates of the pattern have been dispersed uniformly over the surface of the display area. The transformation program has been modified so that the initial and final patterns need no longer contain the same number of coordinates.

This use of the computer for generating and transforming visual patterns makes evident the need for a fast and flexible arrangement for reading in such patterns. The present system for putting coordinates on cards and then on tape for read-in is far from satisfactory. Work has been started on a program to make it possible to "paint" in a pattern, using the CRT and light gun. Also being explored is the possibility of using an area discriminator directed at a

* W. J. Crozier and A. H. Holway, J. Gen. Psychol. 22, 341 (1939).

raster painted on the CRT overlaid with a transparency of the pattern to be read in. If feasible, this latter method of pattern input would be fast and would provide considerable flexibility.

B. W. White

B. Kinetic Depth Effect

A series of studies is being made to determine the conditions under which the two-dimensional projection (e.g., shadow) of a rotating three-dimensional figure is perceived as a rigid coherent figure with depth. This aspect of depth perception, called the kinetic depth effect, is a particularly interesting facet of the human ability to recognize patterns, and seems to imply a considerable amount of complex information processing by the human nervous system. In the present experiments, two-dimensional projections were achieved by frame-by-frame photography of a computer-generated display. The computer selected random three-dimensional figures, computed the positions of each element on each frame, produced the corresponding display on a CRT, and photographed the display. Observers are shown the resulting movie of each rotating figure and are asked to rate the stimulus on a subjective scale of coherence or rigidity, according to the degree to which the parts of the figure seem to maintain the same relative positions as the figure moves.

The results of the initial experiments showed that the number of elements in the figure, the regularity of the positions of the figural elements, and the type of figure are all important determiners of subjective coherence. Two experiments have been completed during the past quarter, one dealing with speed of rotation, and the other with complexity of rotation. Figure 58-1 shows the effect of speed on subjective ratings of coherence for five different figure types: 4, 16, or 64 random dots and 4 or 16 random unconnected lines. The five speeds, expressed in terms of radians per second, were: 0.029, 0.058, 0.115, 0.230, and 0.460. As Fig. 58-1 shows, speed has very little effect on coherence. Only the slowest speed seems to have a differential effect, leading to somewhat lower subjective coherence.

Complexity of rotation was studied by comparing three kinds of rotation: (1) spinning about a vertical axis, (2) spinning about a skew axis at an angle of 45° from the vertical and at the

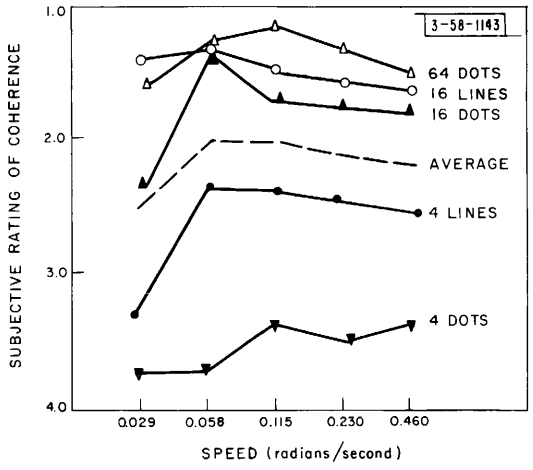


Fig. 58-1. Average subjective rating of coherence (smaller numbers indicate greater coherence) for figure rotating (tumbling) at various speeds. Each point represents the average rating of two stimuli by 14 observers.

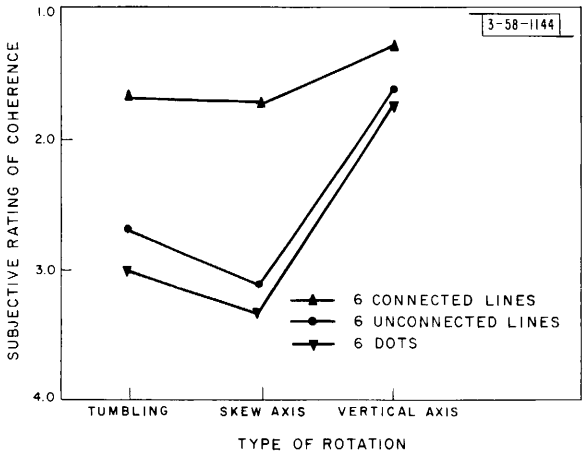


Fig. 58-2. Average subjective rating of coherence for figures undergoing three types of rotation. Each point represents the average rating of two stimuli by 14 observers.

same angle to the plane of the display, and (3) tumbling about a fixed origin, in which the axis of rotation changes in a complex way from frame to frame. The results are shown in Fig. 58-2 for three figures: 6 random dots, 6 random unconnected lines, and 6 random lines connected to form a single closed curve. Spinning about the skew axis appears no better, and perhaps even a bit worse, than tumbling in terms of apparent coherence. This unexpected result has prompted a further experiment now being designed to compare a wider variety of fixed axes of rotation with the more complex tumbling rotation.

B. F. Green, Jr.

C. 16-mm Camera for 709 Display

A camera control mechanism has been designed to allow a Kodak 16-mm Cine Special camera to be used on the IBM 709 computer, in place of the 35-mm Beattie-Coleman camera that is furnished with the computer. The Kodak camera advances a film frame in 66 msec, as compared with more than 500 msec for the Beattie camera. The control logic is almost identical for the two cameras, hence no further adjustments are needed when the Kodak is used. The control mechanism has been built and is being tested.

M. L. Groves

D. Remembering the Present States of a Number of Variables

A series of experiments is being performed to study a type of memory task that is required in many kinds of information-processing systems. One experiment in which the subject was asked to remember the present states of 2, 3, 4, 6, or 8 variables has been completed. He was read a randomly generated list of messages, each saying what state one of the variables had assumed. To insure that he made an important response to each message, he was required to post each one on a status board. The list of messages was interrupted at random by questions, each of which asked for the present state of one of the variables. None of the information on the status board was visible while the subject attempted to answer. He was not told whether his answer was correct and was not encouraged to rehearse the states of the other variables while recording a message or answering a question. The variables either represented several attributes of one abstract "object," in which case each variable had its own exclusive set of four possible states, or represented one attribute of several "objects," in which case all variables ranged over the same set of four states. Results have indicated that the former task is more difficult than the latter.

The data were analyzed further in an attempt to discover how the antecedents of each question affect the probability that it will be answered correctly. Two new facts emerged: (1) the previous state of the variable about which the question inquires affects both the probability of a correct response and the kind of mistake that is likely to occur when the response is not correct; and (2) if the stimuli intervening between the question and the message that provided the correct answer include one or more questions about the same variable – one or more questions that forced the subject to rehearse the information now sought – then the probability of a correct response is improved.

A report on the findings to date has been prepared.*

D. B. Yntema
Gayle E. Mueser

* D.B. Yntema and G.E. Mueser, "Remembering the Present States of a Number of Variables," Group Report 58-2, Lincoln Laboratory, M.I.T. (16 March 1959) (not generally available).

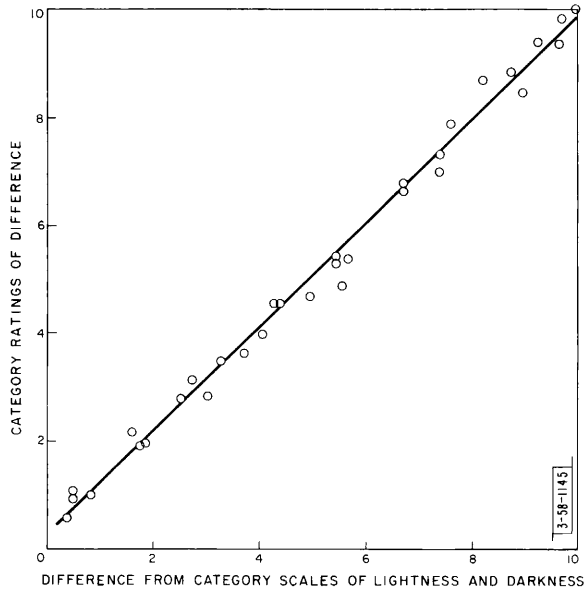
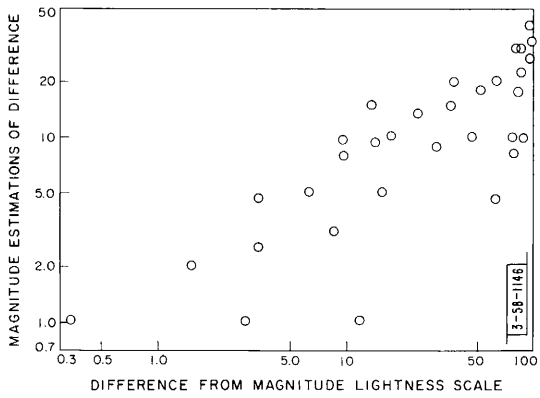


Fig. 58-3. Category ratings of difference vs difference computed from category scales of lightness and darkness.

Fig. 58-4. Magnitude estimations of difference vs difference computed from the magnitude scale of lightness.



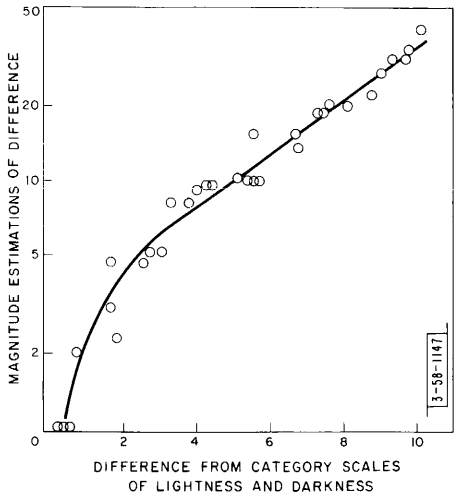


Fig. 58-5. Magnitude estimations of difference vs difference computed from category scales of lightness and darkness.

E. Rote Verbal Learning

A previous study on the serial recall of octal digits has shown that the mean number of pairs of items in a list recalled correctly is doubled every time the number of presentations of the list is doubled, and that it is independent of list length: the frequency distribution of the number of pairs recalled correctly after the n-th trial represents the n-fold convolution of the distribution after the first trial, and the number of exposures necessary to learn all of the items in a list can accordingly be predicted on the basis of performance after the first exposure of a list of any length. These facts seem to be inconsistent with results obtained by other workers on the free recall of English monosyllables.

A study is therefore under way to compare the recall of English monosyllables after various numbers of exposures under three conditions of presentation and recall: (1) serial recall, (2) free recall when the items are presented in the same order every time, and (3) free recall when the items are presented in a different order every time. Some 2000 monosyllables have been selected and arranged in lists, and a preliminary experiment has been performed.

Nancy C. Waugh

F. Quantitative Judgment

Quantitative judgments made by individuals are of two general types: (1) ratio judgments, as, for example, when a person judges that one object feels half as heavy as another, or that one noise sounds ten times louder than another, and (2) interval or distance judgments, as when one color is judged to be midway between two others, or when a particular object is rated "four" on a seven-point equal interval scale. Subjects can make both types of quantitative judgment with considerable reliability and internal consistency. Yet it has been found that scales constructed from ratio judgments are not, in general, linearly related to those constructed from interval or distance judgments.

Several studies concerned with these two types of quantitative judgment have been carried out during the past year. In one study, the methods of magnitude estimation (a ratio method) and category rating (a distance method) were used to construct subjective scales of both whiteness and blackness of Munsell neutral-gray color chips. It was found that the category scales were approximately logarithmically related to the magnitude scales, except near the lower end of the scales. According to the magnitude scales, blackness was the reciprocal of whiteness, whereas for the category scales, blackness was the negative of whiteness. The results are consistent with the notion that judgments in both procedures are based essentially on a single type of perceptual relation, which in the one case is interpreted by the subject as a subjective ratio and in the other as a subjective distance.

In a follow-up experiment carried out during the present reporting period, the two scaling procedures were used to construct scales of the subjective <u>difference</u> between pairs of the same gray stimuli. The category scale of differences was again found to be roughly logarithmically related to the magnitude scale of differences. The directly scaled differences were compared with the numerical differences computed from the original blackness and whiteness scales, with the results shown in Figs. 58-3 and 58-4. It thus appears that, although category ratings of difference are linearly related to differences computed from category scales of whiteness and blackness, the magnitude estimations of difference are not related in any simple manner to the differences computed from the corresponding magnitude scales of blackness or whiteness. Instead, as shown in Fig. 58-5, the magnitude estimations of difference can be expressed as a function (again

roughly logarithmic except at the lower end) of the original category scales. When asked to make magnitude estimations of differences, the subject apparently orders the pairs according to the distance interpretation and then assigns values to the pairs according to the ratio interpretation.

W. S. Torgerson

IV. METHODOLOGY

A. Reliability of Queuing Data

The study of queuing problems, using Monte Carlo procedures, is potentially useful in situations where the rules of the queue are simple to state but their mathematical implications are difficult to derive. However, it has not been sufficiently recognized that this potential cannot be realized unless a valid estimate of the sampling error inherent in Monte Carlo methods can also be obtained. In some cases this is difficult to determine. The difficulty can be overcome by an almost endless "piling up" of data, but this is expensive and it would still be useful to know how to allocate computer time to obtain acceptably reliable data on each problem. A closely related and more important problem is that of predicting the future performance of an actual queuing system on the basis of a period of observation of the system. Here collection of large amounts of data is much more expensive and the reliability problem is very acute.

Some indications of the extent of sampling errors were obtained in connection with a study of a random-input, constant service time queue. As a matter of routine two samples of each condition were taken and, even though each sample contained 16,384 observations, it was observed that the differences between sample waiting-time distributions were so large as to vitiate many of the comparisons for which the study was planned. It was shown that this excess variability was not an artifact, but a real property of this type of data.

Consequently, in this quarter a study has been conducted to determine the reliability of sample waiting-time distributions as a function of sample size and system load (traffic intensity). The measure of deviation of the sample was taken to be the maximum deviation of the sample nonzero waiting-time distribution from the theoretical distribution for that load in the one-channel, random-input, constant service time queue. This measure was used because its distribution in independent sampling from any distribution is known and thus furnishes a base line for comparisons.

Fifty samples at each load 0.25(0.05)0.95 were drawn. Of these, 25 were samples of 4000 nonzero waiting times, and 25 were samples of 1000. The data then consist of 25 maximum deviations for each of two sample sizes at fifteen different loads.

As expected, the maximum deviations for the samples of 4000 are about twice those for samples of 1000. The mean maximum deviation for each sample size is a constant fraction of $1/(1-\alpha)$, where α is the load over the range investigated. The maximum deviation for a load of 0.75 may be expected to be twice that for a load of 0.50.

Analysis of the more detailed behavior of these distributions is in progress.

J. E. K. Smith
Laura Klem

B. Information-Processing Language

Information-Processing Language (I. P. L.) is a special computer-programming language designed by Newell, Shaw and Simon* to aid their work on the computer simulation of human cognitive processes. Their successful computer programs to prove theorems in symbolic logic and to play chess suggest that I. P. L. is a very powerful tool. Programs involving complicated symbol manipulation processes are relatively easy to write, using I. P. L. In particular, models of human cognitive processes can usefully be made in terms of I. P. L. programs.

At present Newell and his co-workers are preparing a version of the language, I. P. L.-V, for use with the IBM 650 and 704 computers. In order to use I. P. L.-V at this Laboratory, a 709 version is currently being coded and checked out. This version is being made compatible with the 650 and 704 versions, to facilitate interchange of programs among laboratories.

B. F. Green, Jr.
Alice K. Wolf

C. A Fortran Program to do Probit Analysis

For many biological systems, the probability of response to a given stimulus is approximately a Gaussian or log Gaussian function of the physical intensity of the stimulus. Consequently, the efficient estimation of the parameters of this function has become a common, recurring problem. A maximum likelihood procedure, probit analysis,† is available and quite satisfactory, except that it involves an iteration procedure that may become quite tedious if fully efficient estimates are desired. For this reason a Fortran program for solving this problem was developed.

In the last quarter this program has been completed and partially checked out. In addition, several different modes of input have been added to accommodate a wider range of possible experiments. At present the output of the program, in addition to the parameter estimates, includes a test of goodness-of-fit, a confidence band for the fitted curve, and various auxiliary statistics.

Arrangements are now being made to make this program available to other users.

Rhoda Resnick
J. E. K. Smith

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* A. Newell and J.C. Shaw, "Programming the Logic Theory Machine," Proceedings of the 1957 Western Joint Computer Conference, February 1957.

† D.J. Finney, Probit Analysis, A Statistical Treatment of the Sigmoid Curve (Cambridge University Press, London, 1952).